



Performance Impacts of Recycling and WMA Production and on Asphalt Fatigue Cracking





Combination of Sustainability Initiatives

High Recycle Content

- Less new binder
- % Asphalt Binder Replaced (ABR) vs. %RAP weight
- Degree of mixing?
- Cracking/durability is highest concern

Warm Mix Asphalt

- Sometimes less asphalt binder content than HMA
- Cracking is less of a concern
- Affect aging and blending? For the Better?
- Same performance in the medium / long term?





EDC-1 WMA Performance Metrics

- 1. 40 State DOTs and all Federal Lands Divisions will have a specification &/or contractual language that allows WMA on Federal-aid or Federal Lands projects.**
 - ✓ 41 States + all FLHD (Complete)**

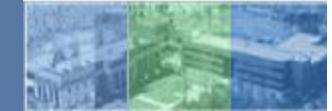
- 2. By December 2012, at least 30 State DOTs will have achieved set targets for WMA usage.**
 - 18 Total with set usage goals**



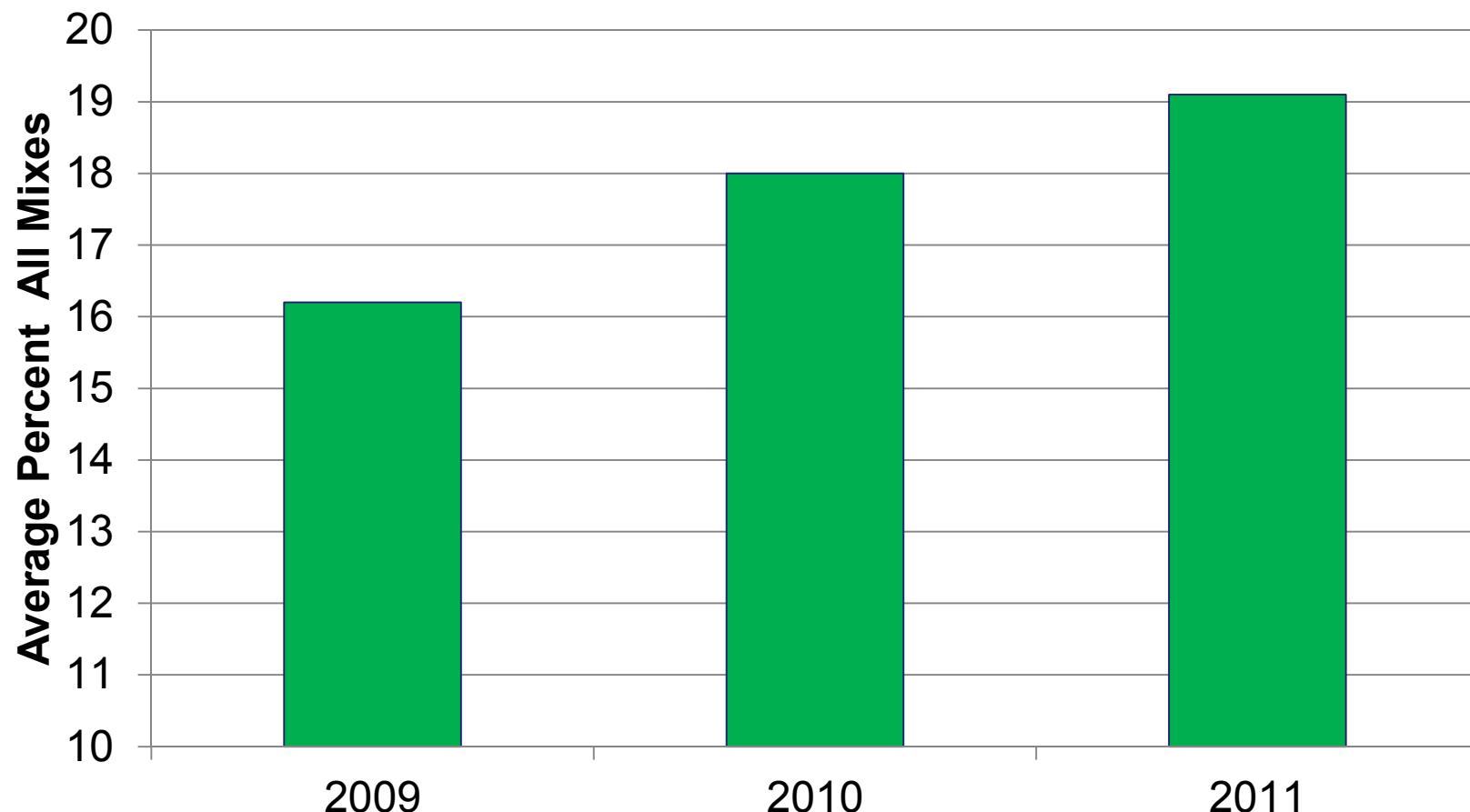
New LTPP WMA Project

- Establish framework & Expand LTPP to include WMA experiments
 - ◆ New SPS-10 Experiments
 - AC overlay of existing AC
 - HMA, WMA w/foam, WMA w/chemical
 - 16 - variety of climate and traffic
 - Warm mix production and laydown temperatures
 - RAP included
 - ◆ Expand GPS experiment with Existing LTPP test sections receiving WMA overlay



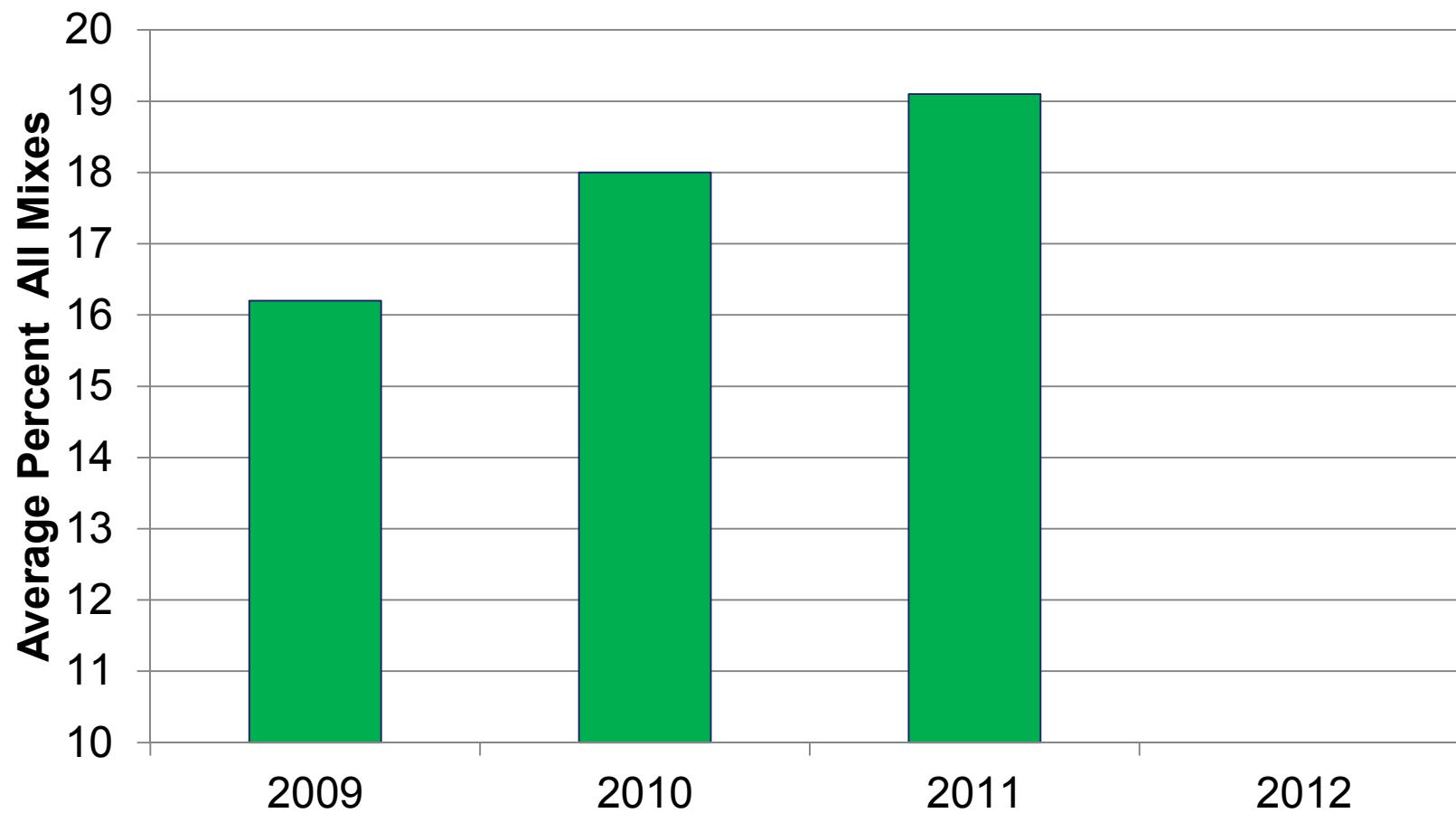


RAP Usage from NAPA Survey





RAP Usage from NAPA Survey





Objectives of this Experiment

- *Establish realistic boundaries* for high-RAP mixes employing WMA technologies and RAS mixes based on *percent binder replacement* and *binder grade changes* when combined together.





ALF Experimental Design

	HMA / WMA Production Temperature	300°F - 320°F	240°F - 270°F	
Recycle Content		-	Foam	Chem.
0%		PG64-22	-	-
20% ABR RAP ≈ 23% by weight		PG64-22	PG64-22	PG64-22
20% ABR RAS ≈ 6% Shingle by weight	PG64-22	PG58-28		
40% ABR RAP ≈ 44% by weight	PG64-22	PG58-28	PG58-28	PG58-28



Outcomes

- Material selection guidelines that provide equivalent performance to current mixtures
- Identify asphalt mixture laboratory tests_ that capture structural fatigue cracking

ALL Validated with full-scale accelerated pavement tests

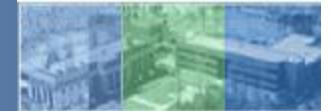
- Performance Based Mix Design
- Calibration Section for HMA Performance Related Specification (HMA PRS)



ALF Experimental Design

- Same general mix design; 4-inch thick asphalt, 12.5mm NMAS (2 lifts)
- Asphalt binders PG64-22 & PG58-28
- 26-inch thick aggregate base
- Controlled 20°C temperature
- 14,000 pound single wheel load (legal axle)
- Programmed lateral wheel wander

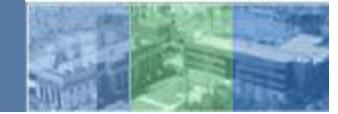




FHWA Pavement Test Facility

- Accelerated Pavement Testing
- Accelerated Load Facility





Characteristics of Recycled Asphalt Materials

RAP

- 13 samples taken as stockpile was built
- 4.7% average AC content by solvent
 - 0.2% std. dev. AC
- TCE Recovered PG
 - PG89.4-21.7
 - ITPG 29.1C

RAS

- Tear-Offs
- 99.4% Passing ½" sieve
- 85.2% Passing #4 sieve
- 20.9% AC by solvent
- High Temp >>> PG140



Dedicated RAP and RAS stockpiles for the Project



Go / No-Go Test Strips



- Produce mix (+ sufficient plant waste) in the A.M.
- Store in the silo
- Place 2-inch lift test strip in Parking Lot
- ~3 Hours for Accept / Reject Test



Go / No-Go Test Strips



- **If Accepted** – place mix in the ALF lanes during the afternoon with stored silo mix
 - Repeat same sampling and quality tests
-
- **If Rejected** - Try another day
 - Adjust plant and laydown

Sampling Per Lane

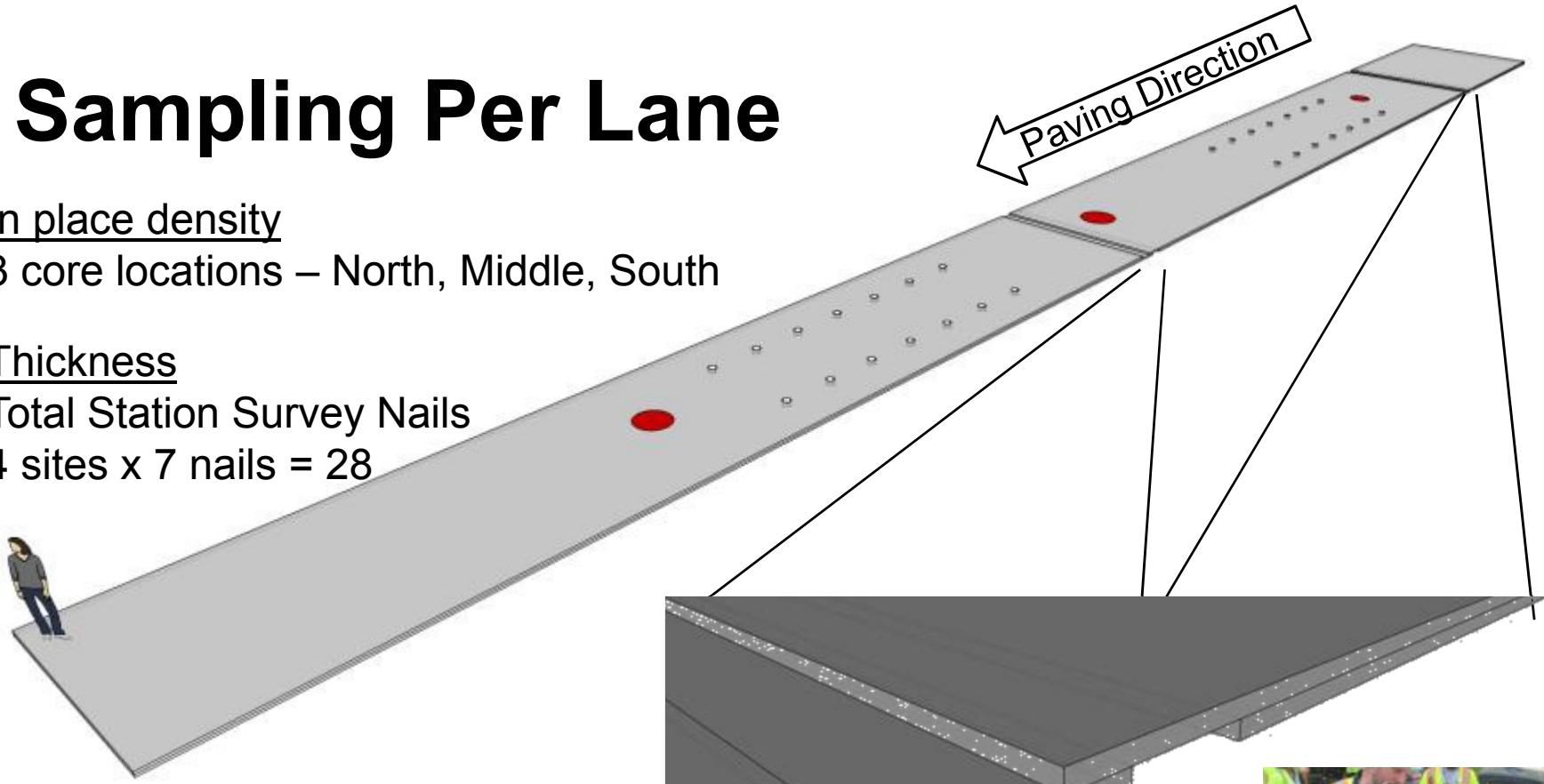
In place density

3 core locations – North, Middle, South

Thickness

Total Station Survey Nails

4 sites x 7 nails = 28



Volumetrics

Sampled behind-the-paver

12 ft x 1 ft plate samples

2 locations

Upper and Lower Lifts

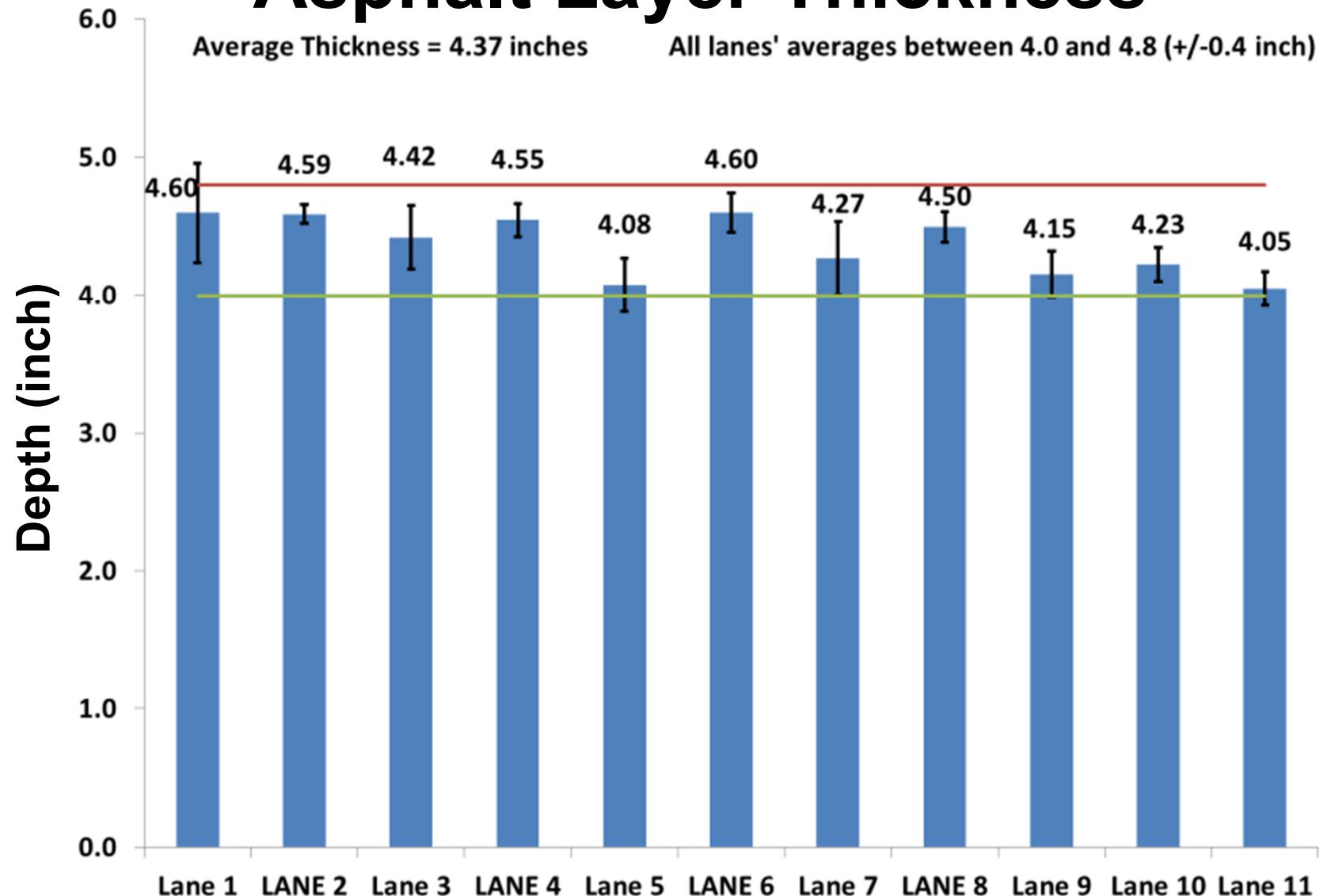
4 buckets each plate

8 buckets to FHWA & 8 to Contractor





Asphalt Layer Thickness





Temperature of the Mix

Drum Exit / Slat Conveyor

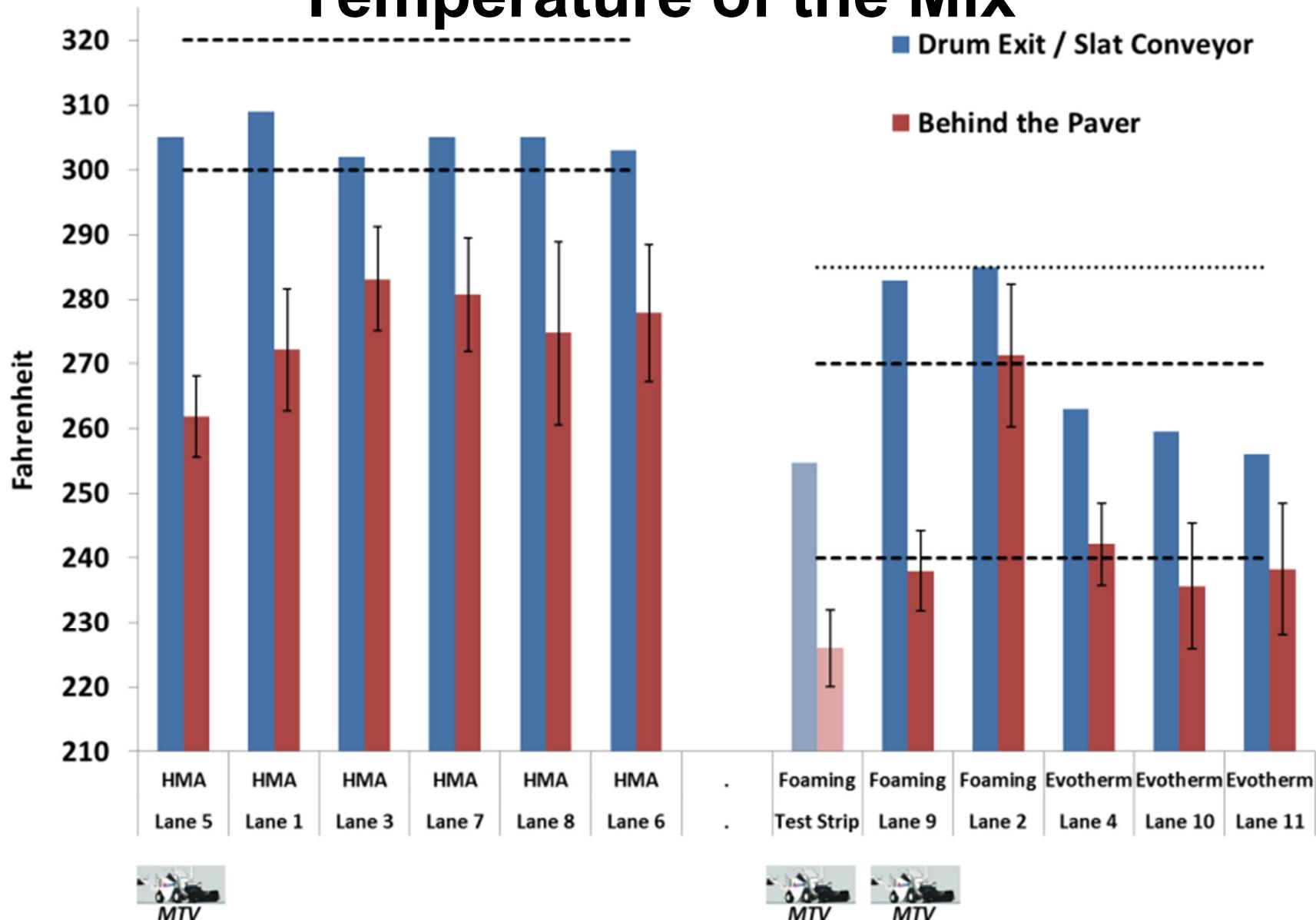


Behind the Paver



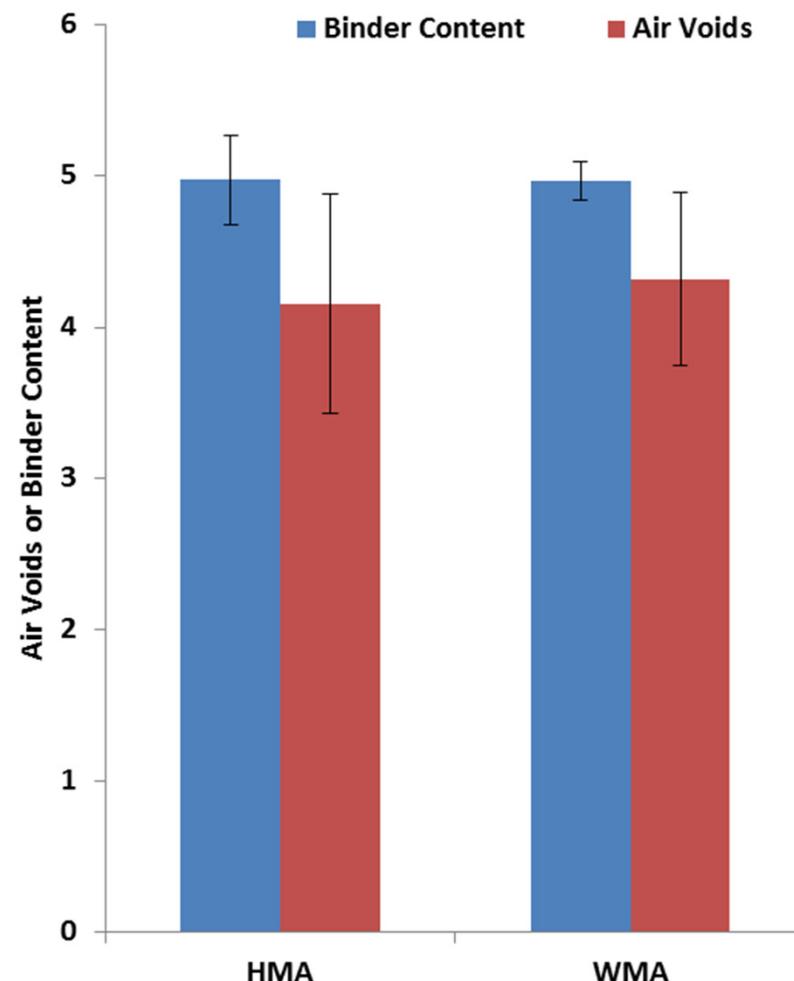
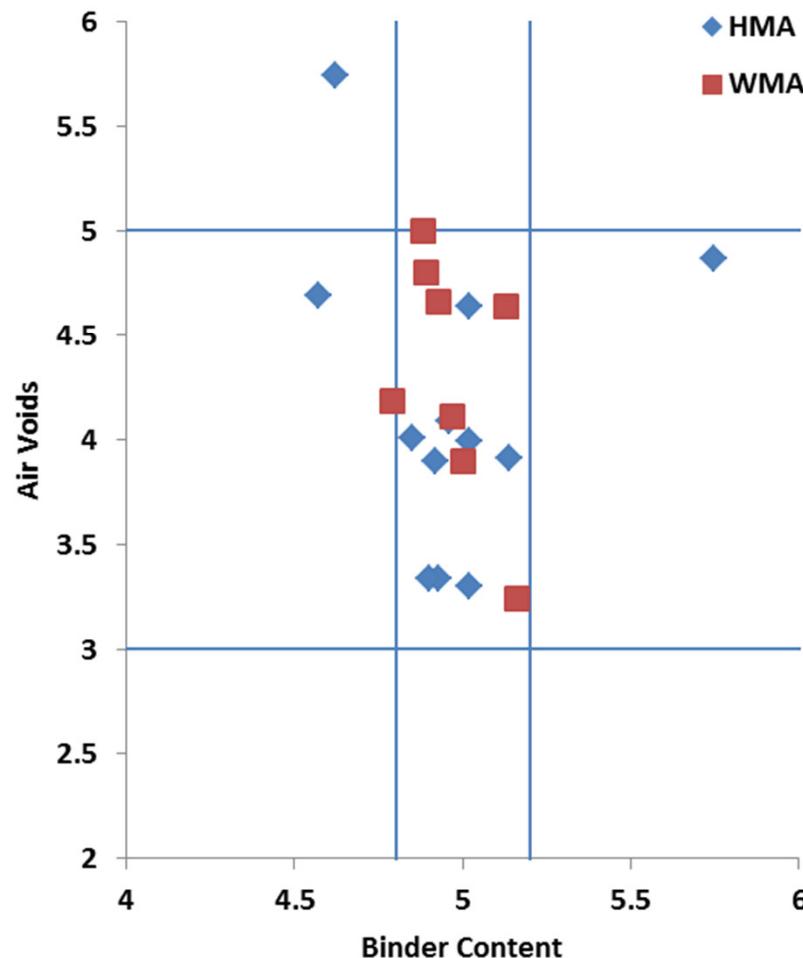


Temperature of the Mix





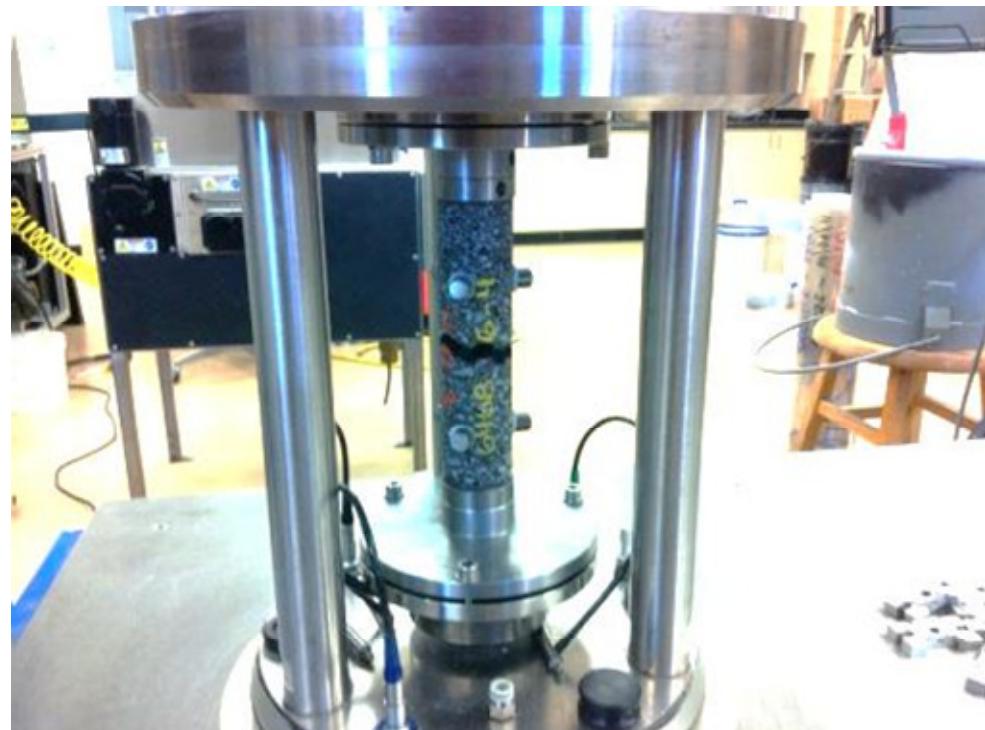
Consequence of WMA “Drop-In” to HMA Design



** Local Diabase Aggregate Water Absorption: 0.3% Coarse Stockpiles
0.5% & 1.4% Fine Stockpiles



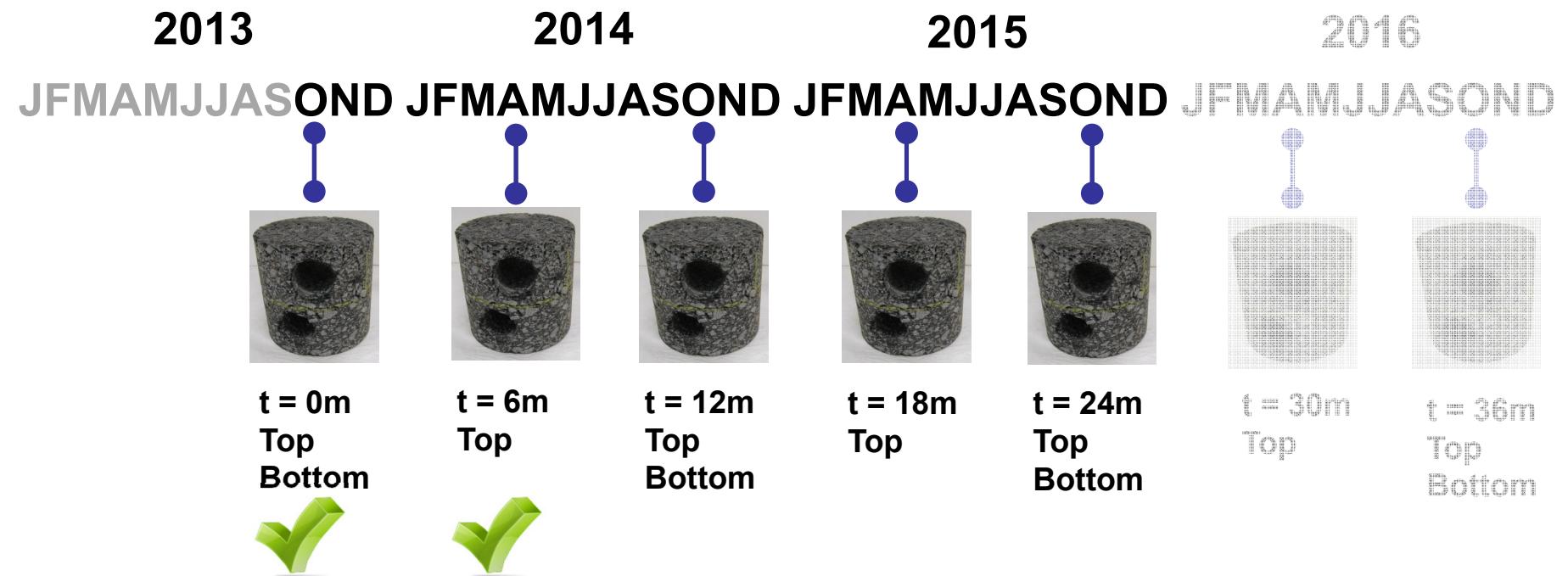
Post Construction, As-built $|E^*|$ and Fatigue Using Reduced-Scale Specimens



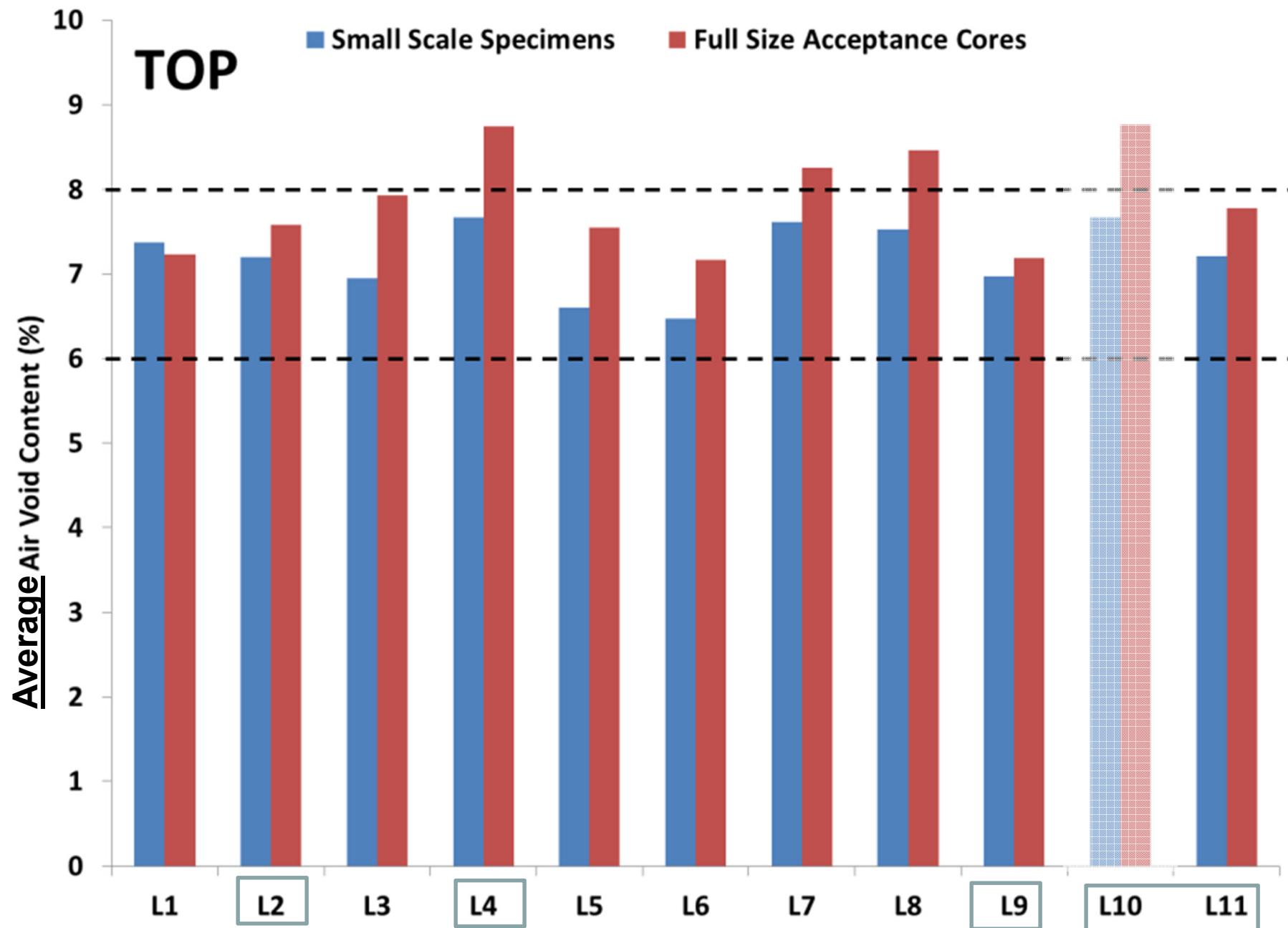
- See
 - Kutay et al. (2009), Transportation Research Record TRR # 2127*
 - Li & Gibson (2013), Journal of the Assoc. of Asphalt Paving Tech., Vol. 82*

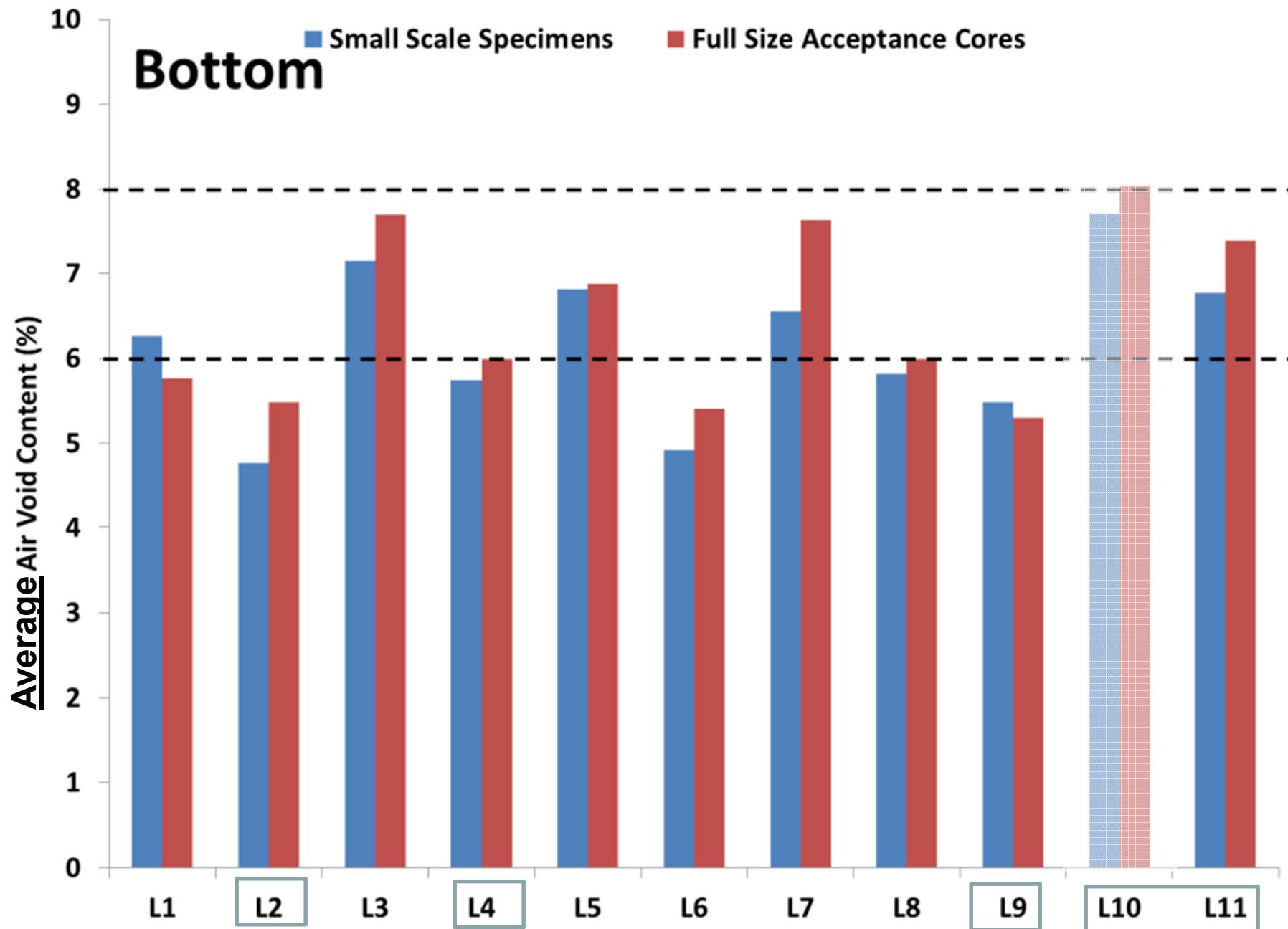


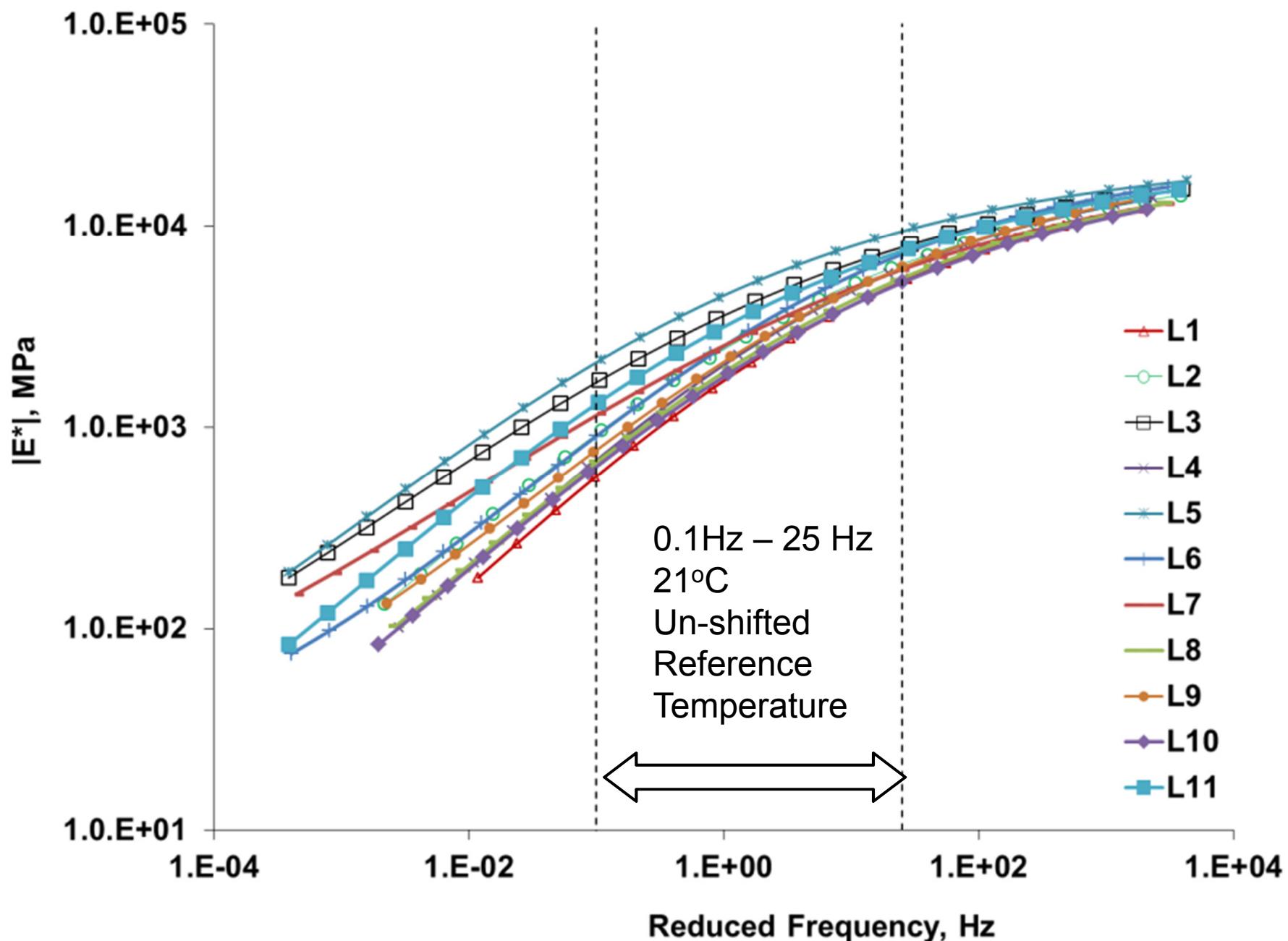
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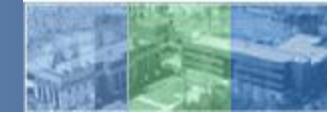


First round of $|E^|$ & Fatigue characterization of All 11 lanes
2 work weeks each; 4 weeks total*









Effect of Recycle Content

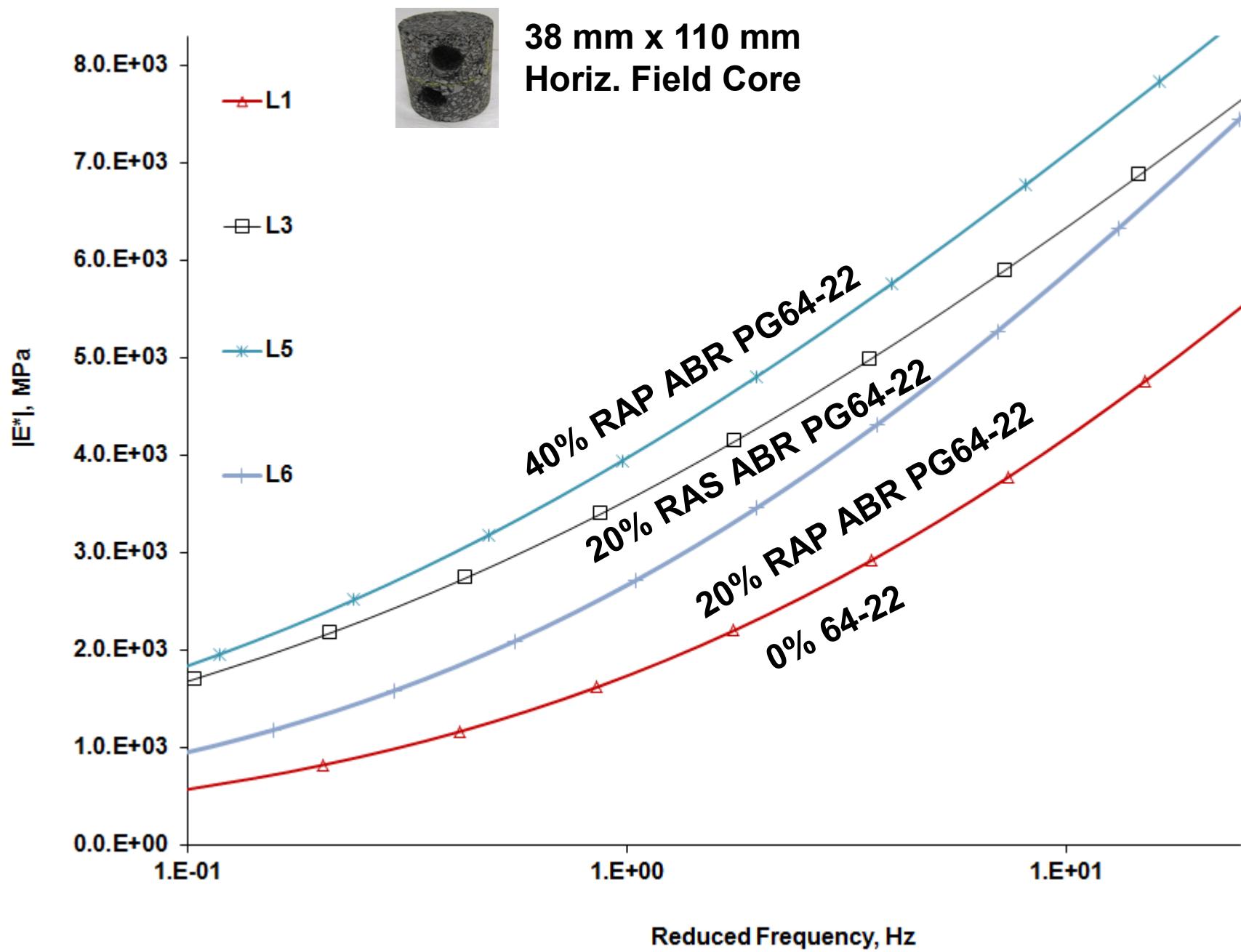
Recycle Content	HMA / WMA Production Temperature	300°F - 320°F		240°F - 270°F	
		Foam	Chem.	Foam	Chem.
0%		-	-	-	-
20% ABR RAP ≈ 23% by weight		PG64-22		PG64-22	PG64-22
20% ABR RAS ≈ 6% Shingle by weight		PG64-22	PG58-28		
40% ABR RAP ≈ 44% by weight		PG64-22	PG58-28	PG58-28	PG58-28

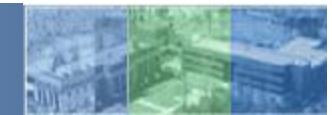
Recycle Content

HMA / WMA
Production Temperature

Warm Mix Technology







Effect of Offset with Softer Binder PG

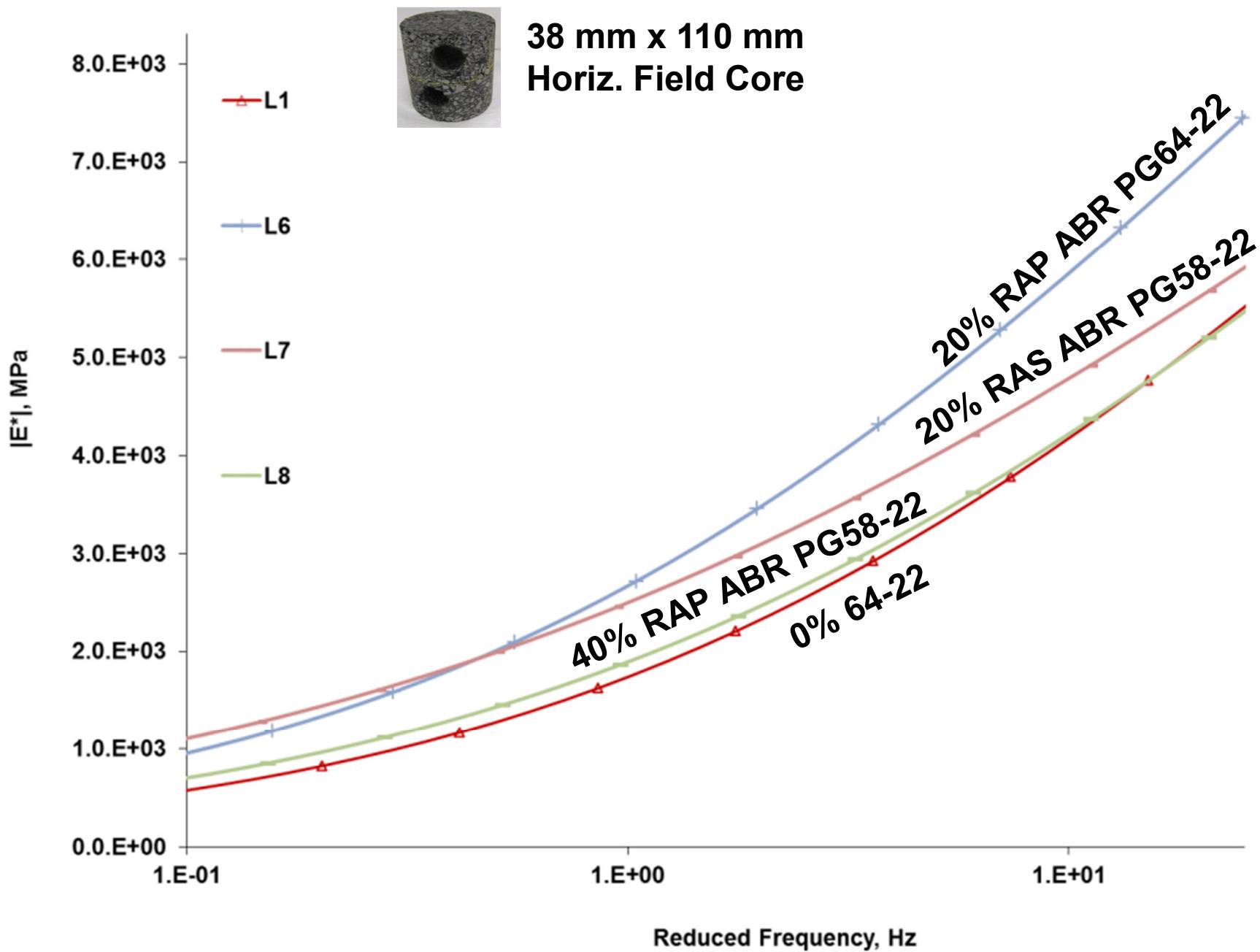
	300°F - 320°F	240°F - 270°F	
	-	Foam	Chem.
0%	PG64-22	-	-
20% ABR RAP ≈ 23% by weight	PG64-22	PG64-22	PG64-22
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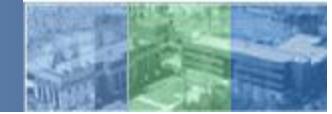
Production Temperature

HMA / WMA

Warm Mix Technology

Recycle Content

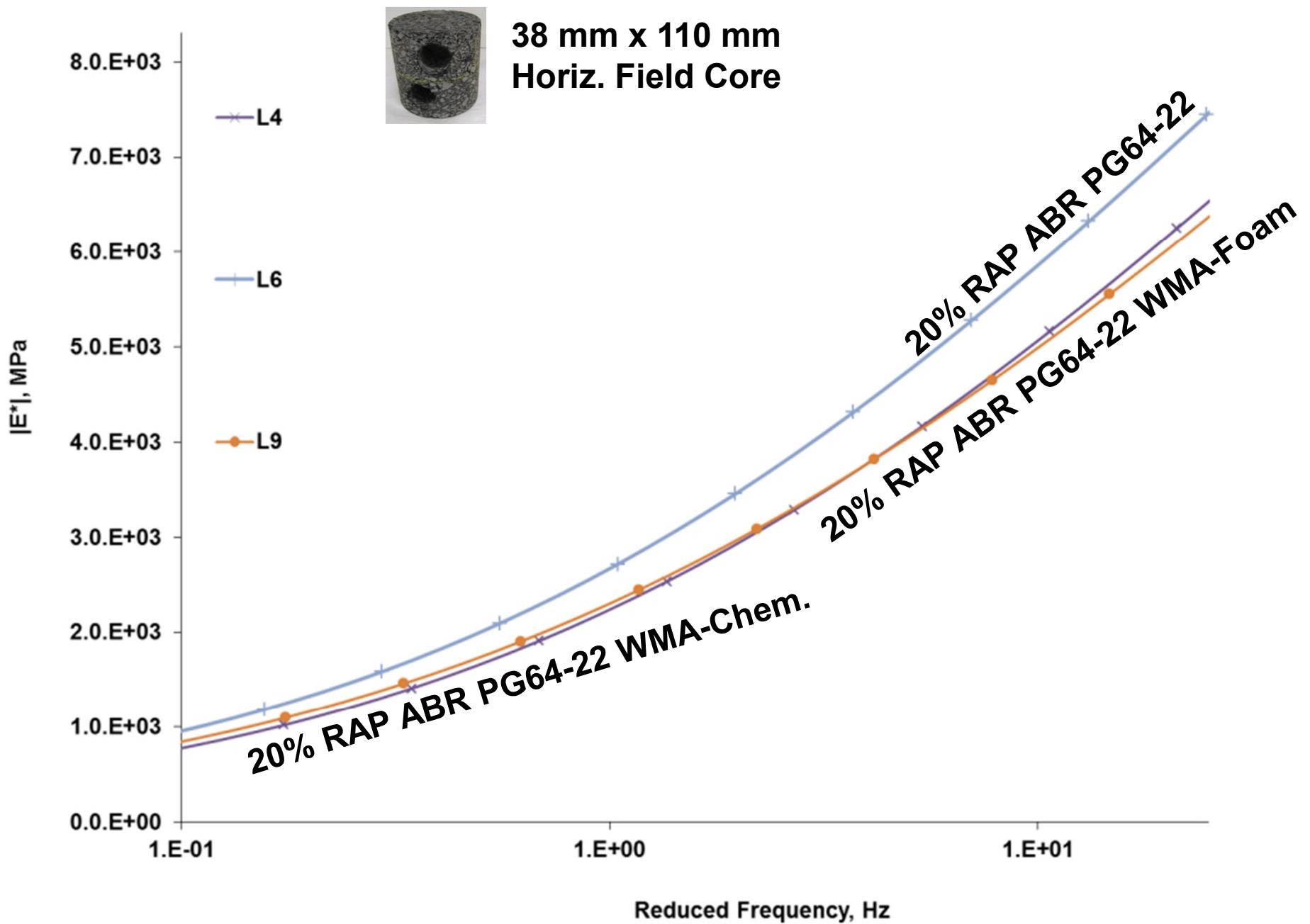


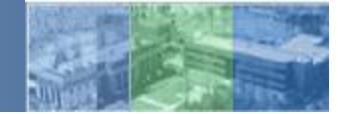


Effect of WMA (1 of 2)

	300°F - 320°F	240°F - 270°F	
	-	Foam	Chem.
0%	PG64-22	-	-
20% ABR RAP ≈ 23% by weight	PG64-22	PG64-22	PG64-22
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Production Temperature
HMA / WMA
Warm Mix Technology
Recycle Content

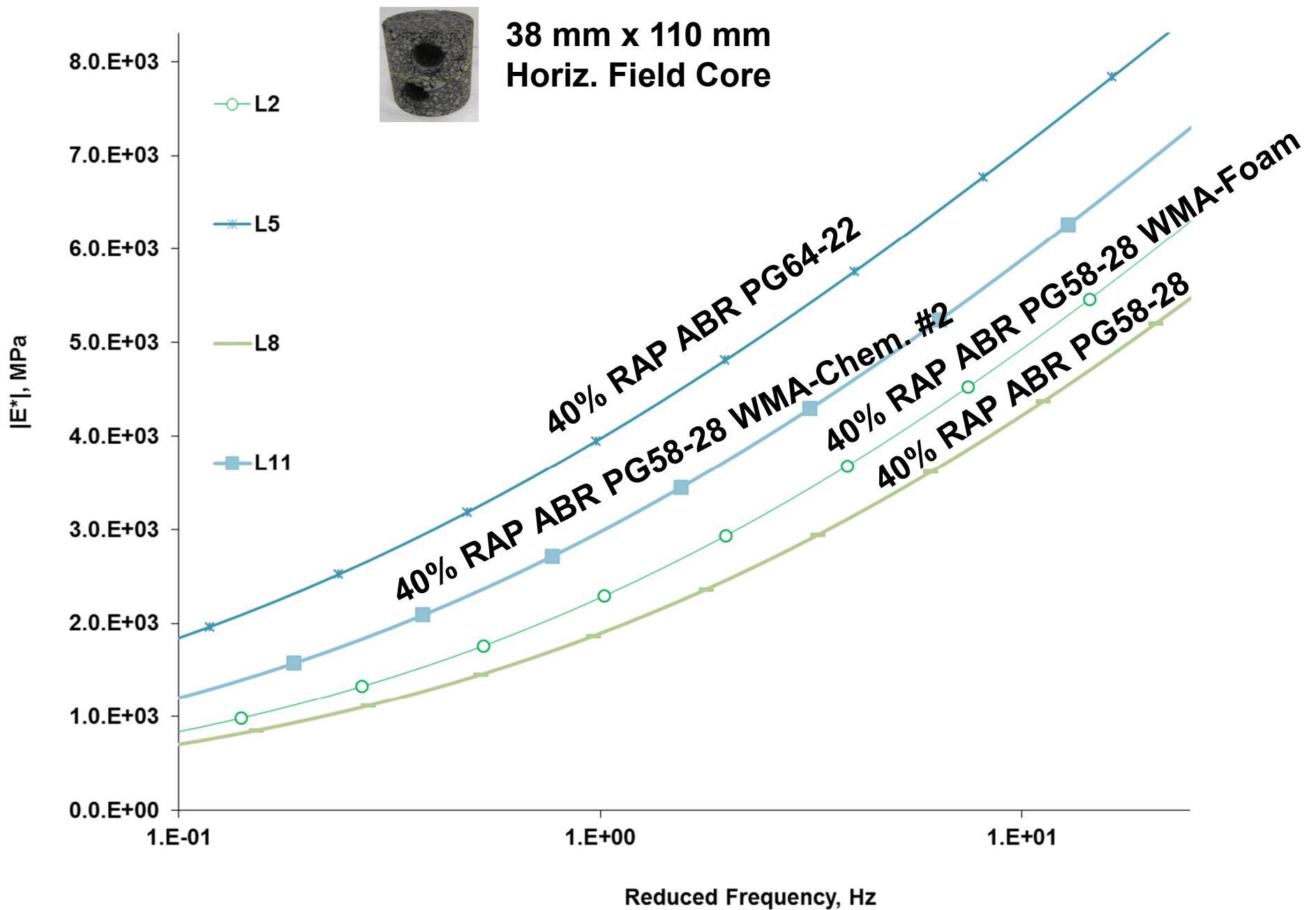




Effect of WMA (2 of 2)

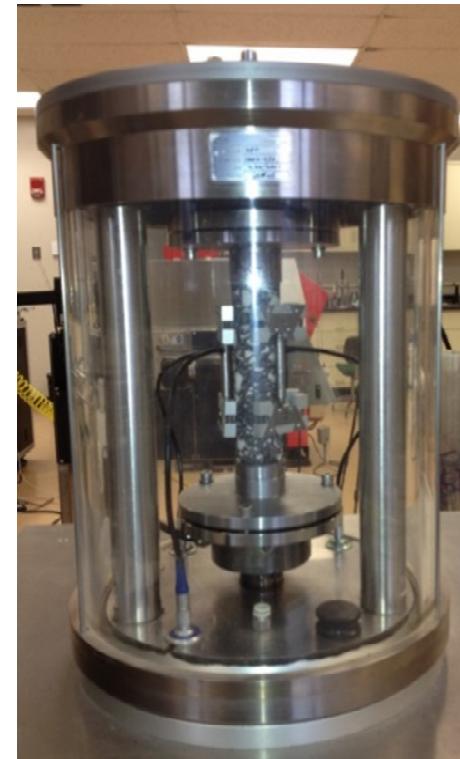
	300°F - 320°F	240°F - 270°F	
	-	Foam	Chem.
0%	PG64-22	-	-
20% ABR RAP ≈ 23% by weight	PG64-22	PG64-22	PG64-22
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40% ABR RAP ≈ 44% by weight	PG64-22	PG58-28	PG58-28

The table illustrates the effect of Warm Mix Asphalt (WMA) on asphalt grade (PG) based on production temperature and recycle content. A green arrow points from the 40% ABR RAP row to the rightmost column, indicating the shift in asphalt grade from PG64-22 to PG58-28.

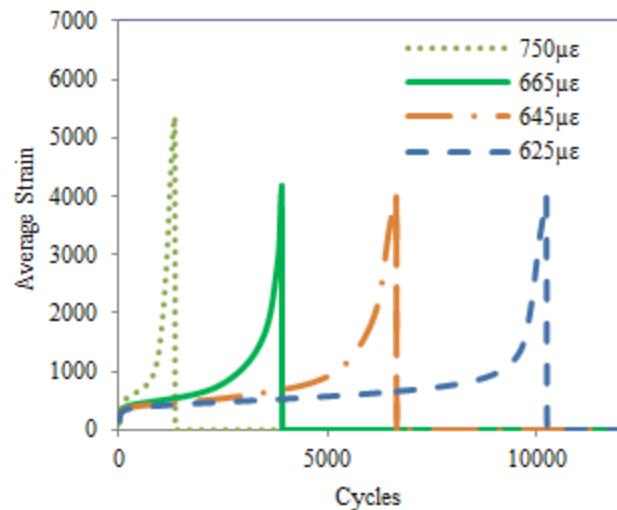




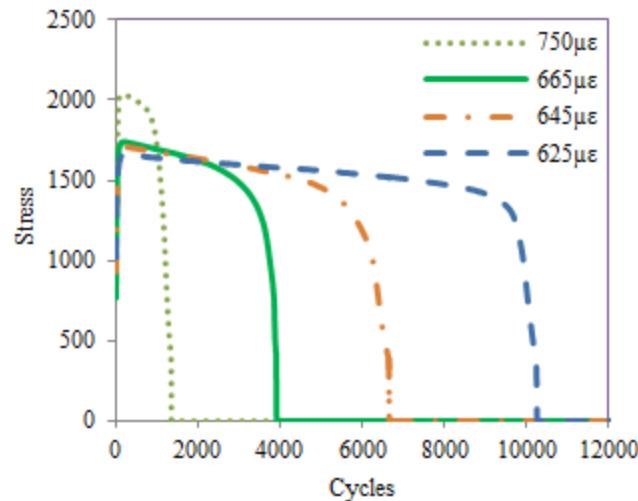
AASHTO TP107 *Determining the Damage Characteristics Curve of Asphalt Mixtures from Direct Tension Cyclic Fatigue Tests*



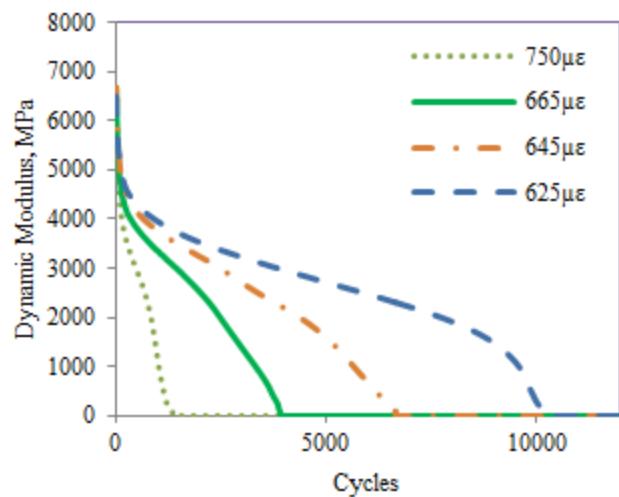
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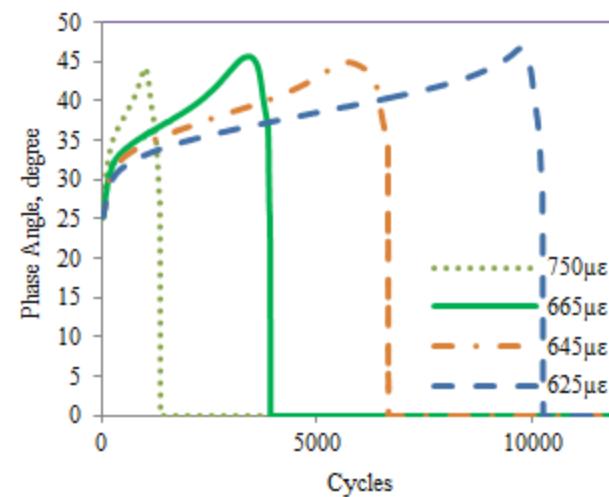
(a)



(b)



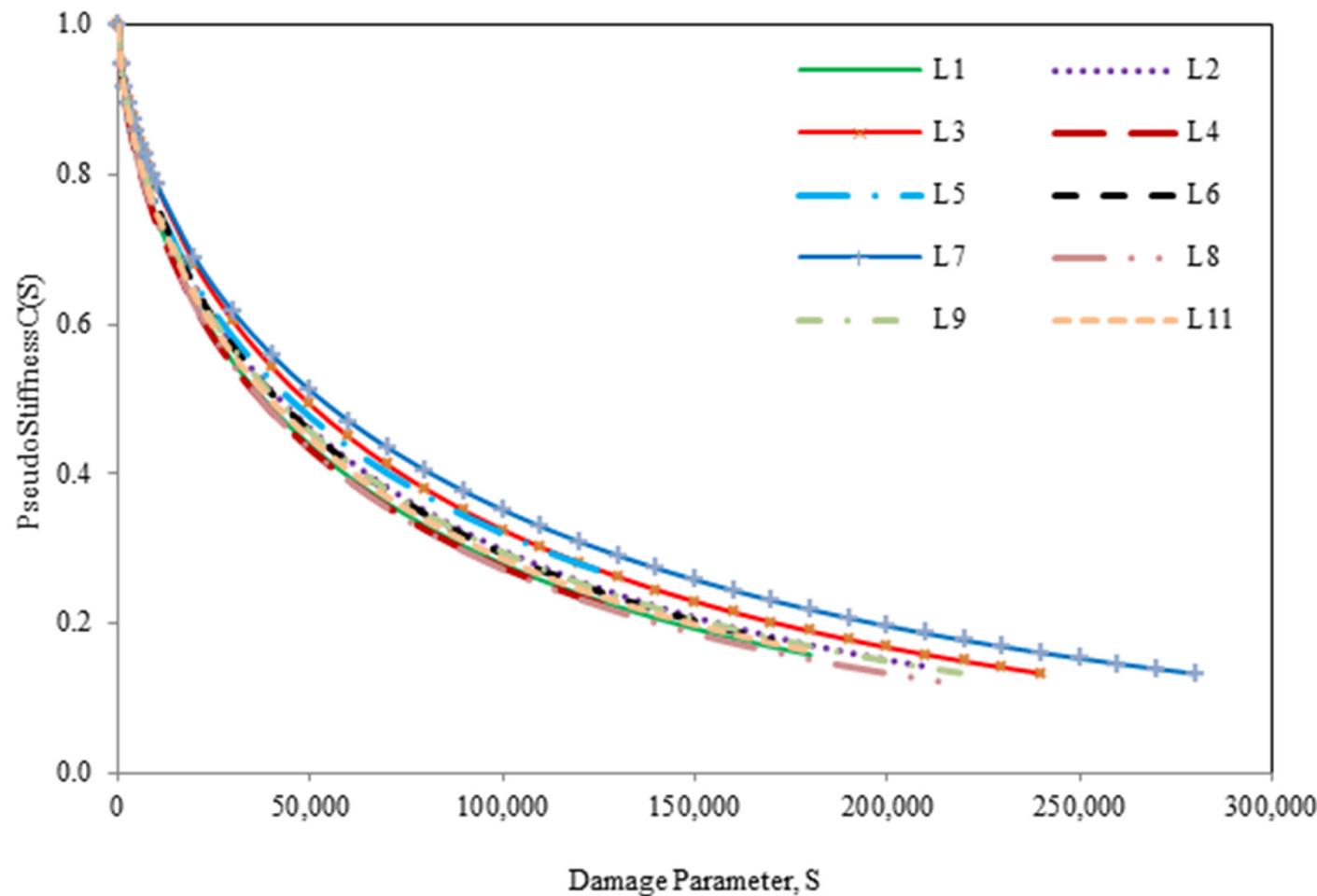
(c)



(d)



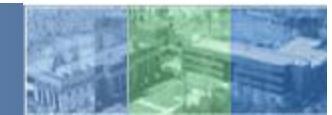
Damage Characteristic Curve





Strain ($\mu\epsilon$) Levels Scenarios Used in VECD Fatigue Predictions

Scenario	Scenario Description		L1	L2	L3	L4	L5	L6	L7	L8	L9	L11
A	Fixed 4.5-inch HMA thickness and fixed base modulus		418	356	299	374	267	335	362	396	380	313
B	Individual Lanes' average HMA thickness and base modulus		346	308	304	337	318	288	371	396	437	401
C	Scenario B w/ thickness and modulus variability	Thick on Stiff	311	288	284	309	301	268	318	358	396	371
D		Thin on Soft	388	340	327	362	348	317	432	429	471	447
E	Fixed 10-inch HMA thickness & fixed base modulus		159	133	110	139	95	122	134	150	145	114



Performance Ranking, 1=Best

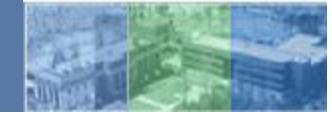
Test	Scenario	L1	L2	L3	L4	L5	L6	L7	L8	L9	L11	τ_k	% sig
Field Core	A	5	8	4	1	9	3	2	7	6	10	0.11	28%
	C	2	5	8	1	6	3	4	7	9	10	-0.11	28%
	B	3	4	6	1	9	2	5	7	8	10	-0.16	40%
	D	3	4	5	1	9	2	7	6	8	10	-0.16	40%
Unaged Full-size	*A	9	5	3	8	10	7	2	1	4	6	*1	*100%
	C	5	3	6	7	10	4	1	2	8	9	0.47	92%
	B	5	3	6	7	10	4	2	1	8	9	0.47	92%
	D	6	2	5	7	10	3	4	1	8	9	0.47	92%
Unaged Small-size	A	9	2	1	8	10	4	6	5	7	3	0.51	96%
	C	4	1	2	7	10	3	5	6	9	8	0.16	40%
	B	4	1	3	6	10	2	7	5	9	8	0.11	28%
	D	4	1	3	5	10	2	7	6	9	8	0.11	28%
Aged Full-size	A	9	2	5	10	8	6	7	3	1	4	0.38	84%
	C	3	1	7	8	9	2	5	4	6	10	0.20	52%
	B	3	1	5	8	9	2	7	4	5	10	0.11	14%
	D	3	1	7	6	9	2	8	4	5	10	0.02	0%
Aged Small-size	A	9	7	2	10	4	8	6	1	3	5	0.51	96%
	C	6	2	5	8	9	3	4	1	7	10	0.47	92%
	B	5	2	4	9	8	3	6	1	7	10	0.33	78%
	D	5	2	4	8	9	3	7	1	6	10	0.33	78%



Performance Ranking, 1=Best

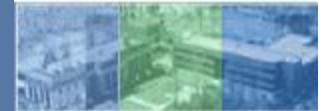
Lane	Mixture Type		Overall Average Rank (Table 11)	Rank from Reference Condition
L2	40% RAP RBR WMA Foam	PG58-28	2.9	5
L6	20% RAP RBR HMA	PG64-22	3.4	7
L8	40% RAP RBR HMA	PG58-28	3.7	1
L3	20% RAS RBR HMA	PG64-22	4.6	3
L1	0% RBR HMA	PG64-22	5.1	9
L7	20% RAS RBR HMA	PG58-28	5.1	2
L4	20% RAP RBR HMA Chemical	PG64-22	6.3	8
L9	20% RAP RBR WMA Foam	PG64-22	6.7	4
L11	40% RAP RBR HMA	PG58-28	8.5	6
L5	40% RAP RBR WMA Chemical	PG64-22	8.9	10





Take-Aways

- 1. Production of the mixes matched the desired experimental design...small quantities**
- 2. Specifications were tight and some mixes were rejected in order to get them produced correctly**
- 3. High ABR mix was produced without RAP fractionation**
- 4. No single technology (RAP, RAS, WMA) was more or less compactable than others except the WMA-foamed mix temperature needed to be increased by 15C.**



Take-Aways

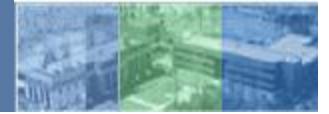
- 5. Increasing ABR stiffened the mixes**
- 6. Softer Virgin PG that is one grade lower on both the high and low end softened the high ABR mixes and the RAS mix**
- 7. Reduced temperature WMA production decreased the stiffness of the mix but is less clear at High ABR.**
- 8. Laboratory and Full-scale APT testing is still ongoing**



Questions?

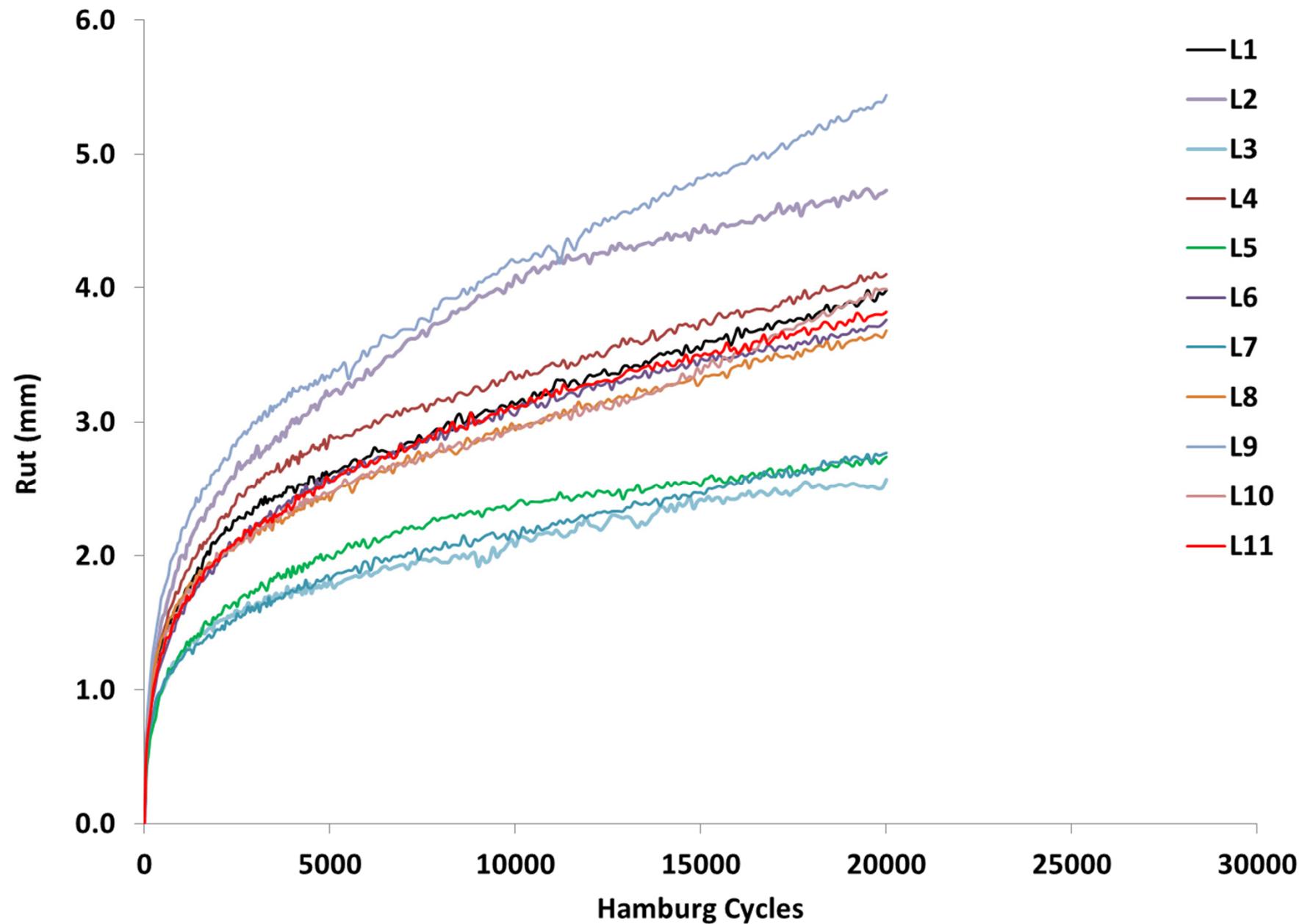
Comments?

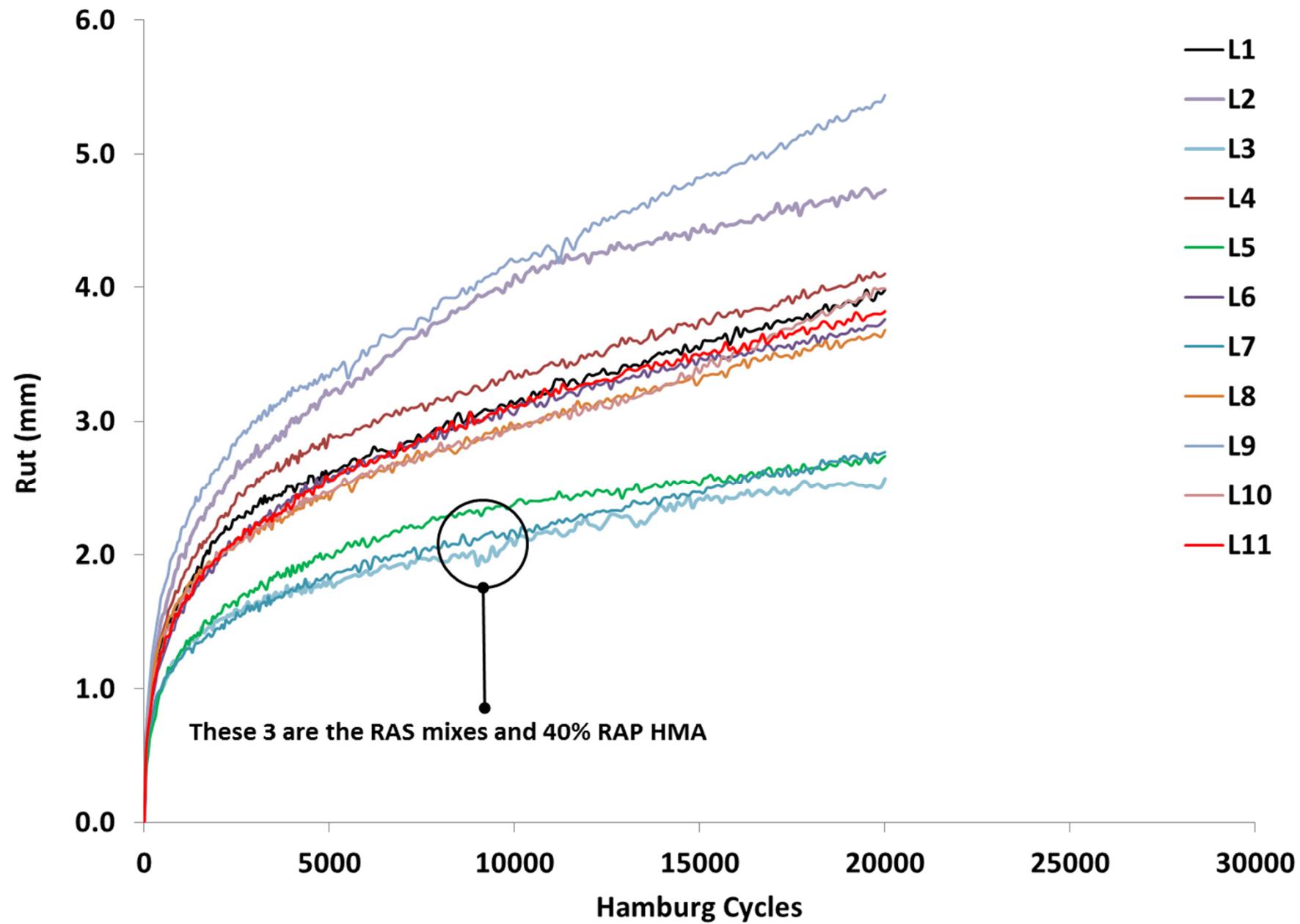


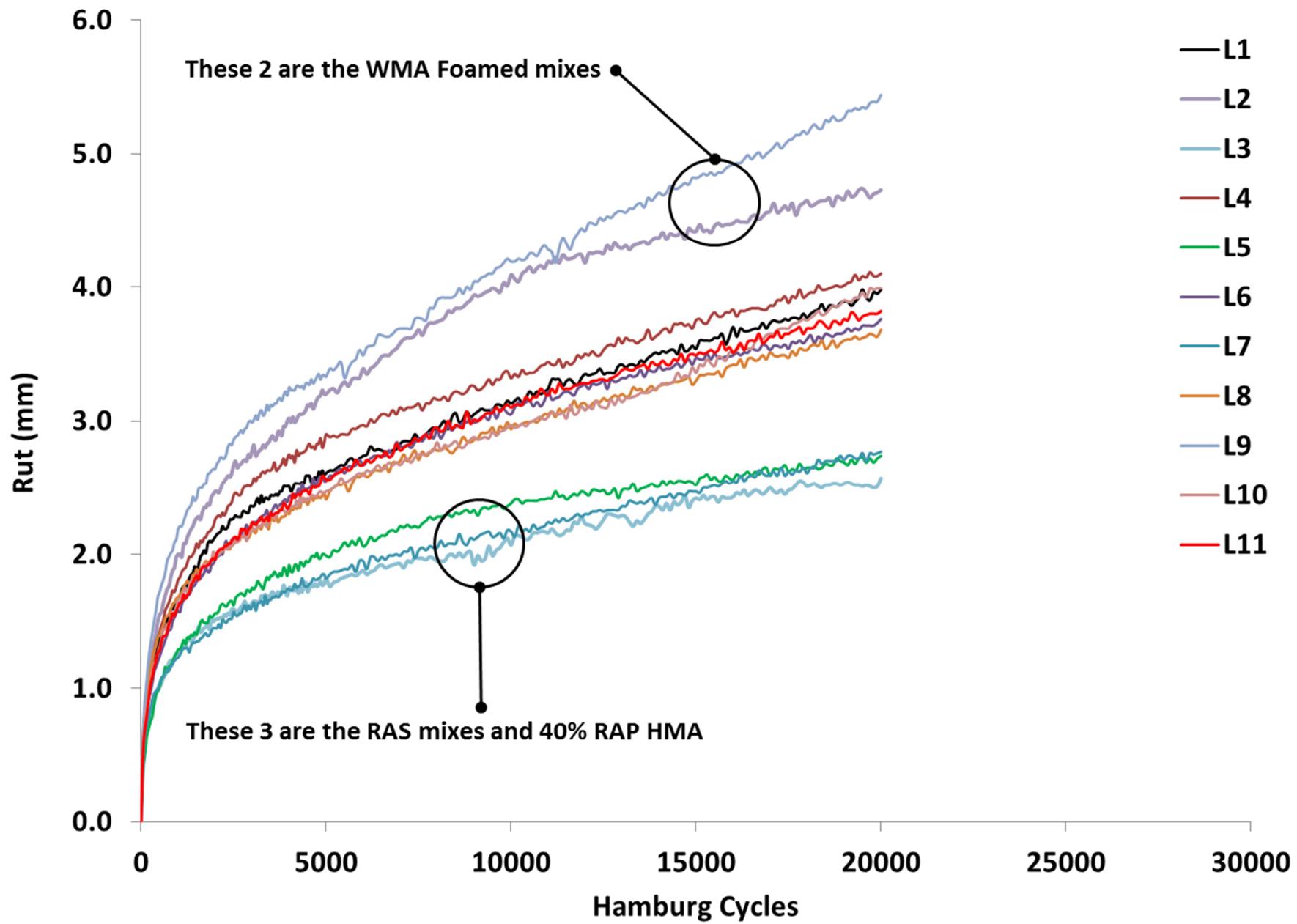


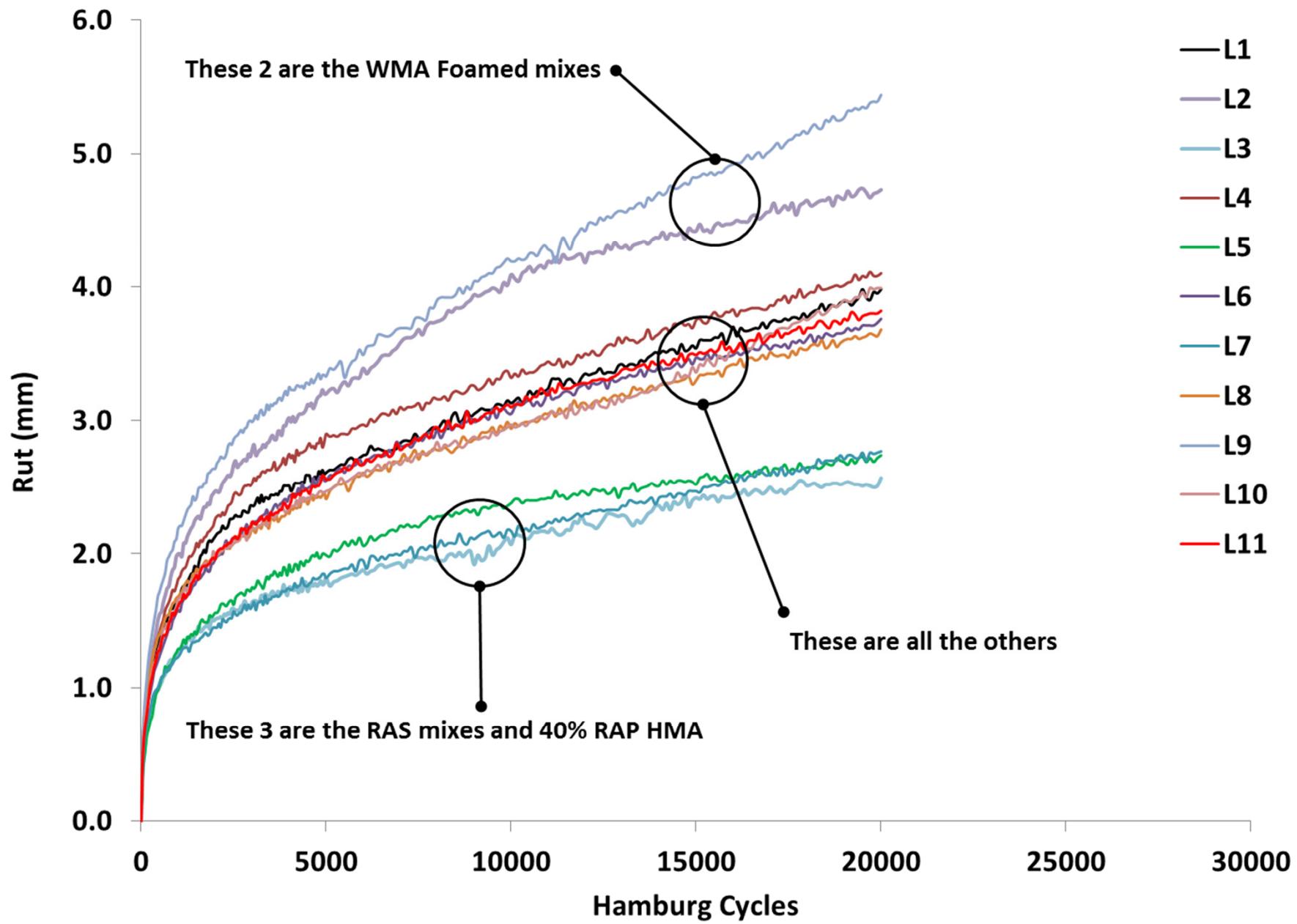
Hamburg Wheel Tracking

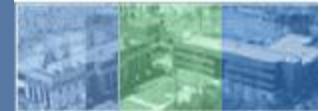








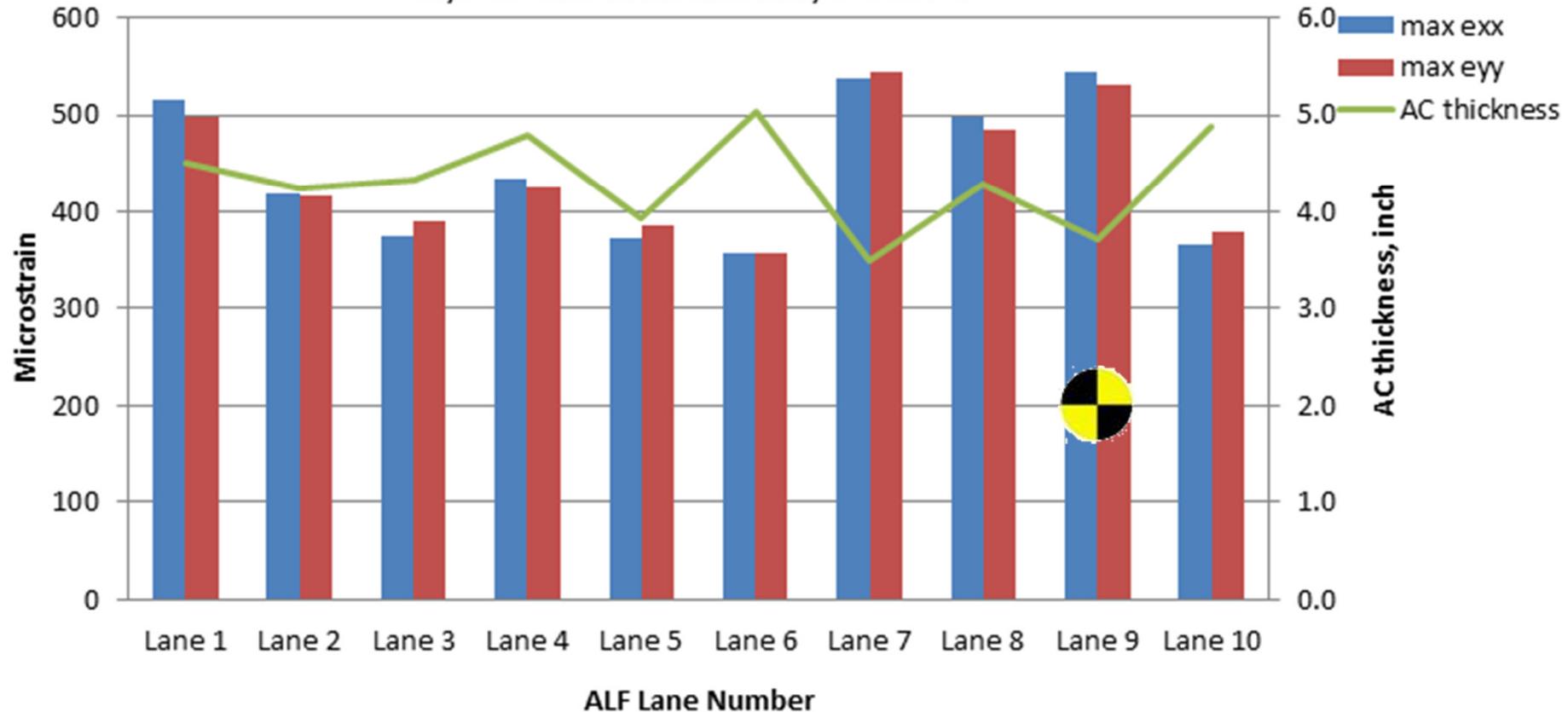




Structural Analysis

Horizontal tensile strains at the bottom of AC layer

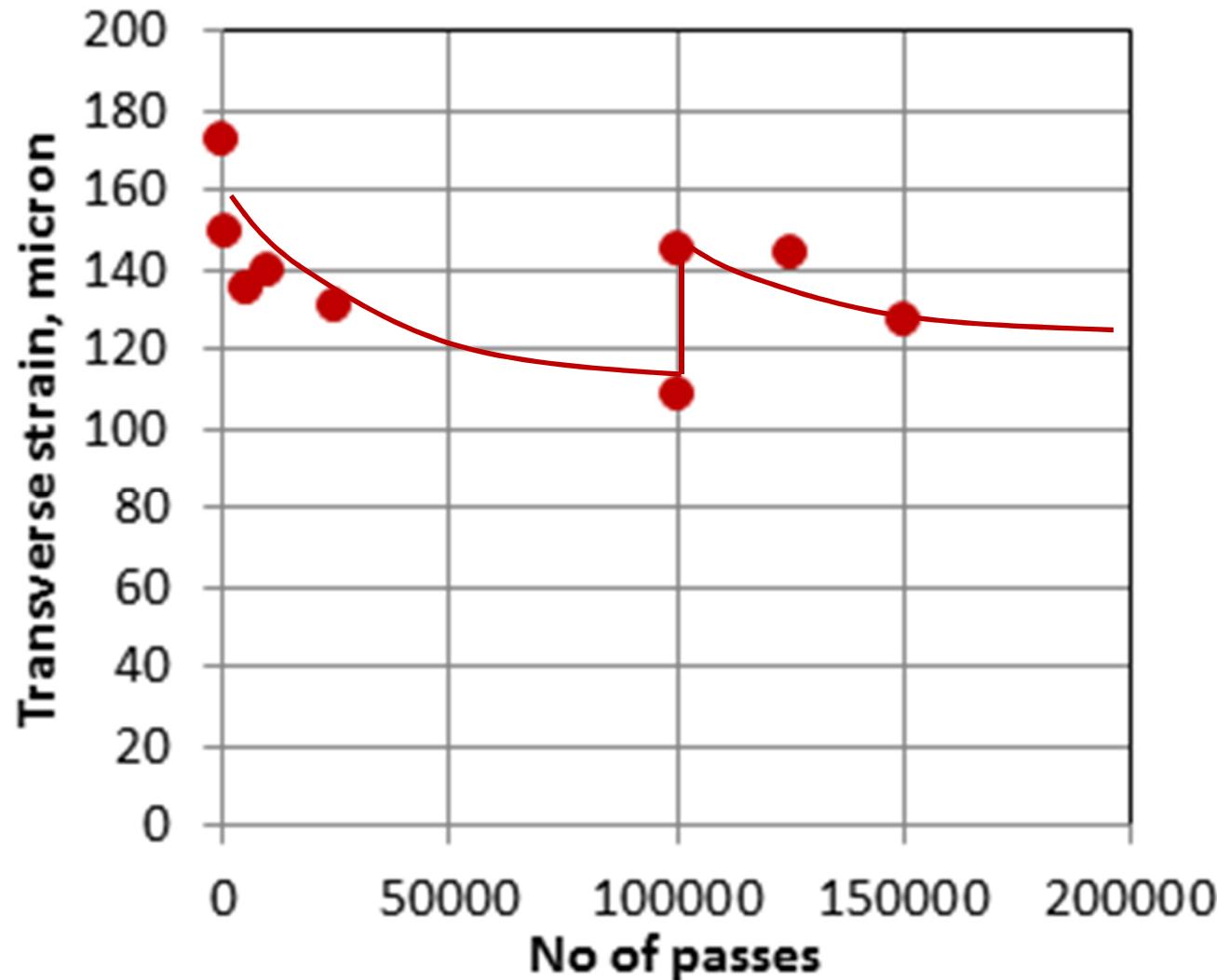
Layered linear viscoelastic analysis on site 2



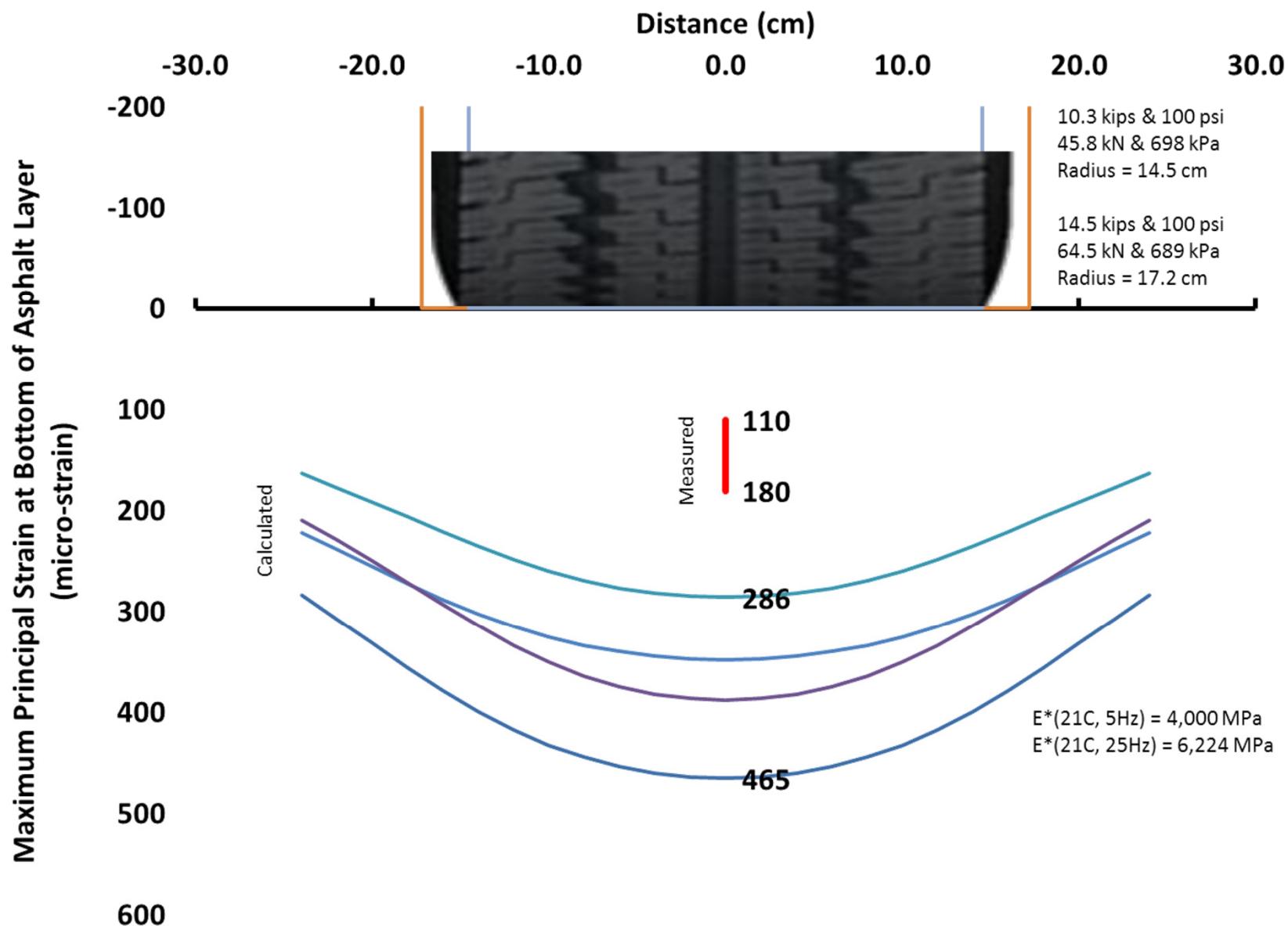
Thus far the trends in strains tend to follow the trends in modulus

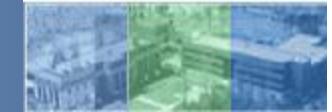


Responses and Performance in ALF Shakedown

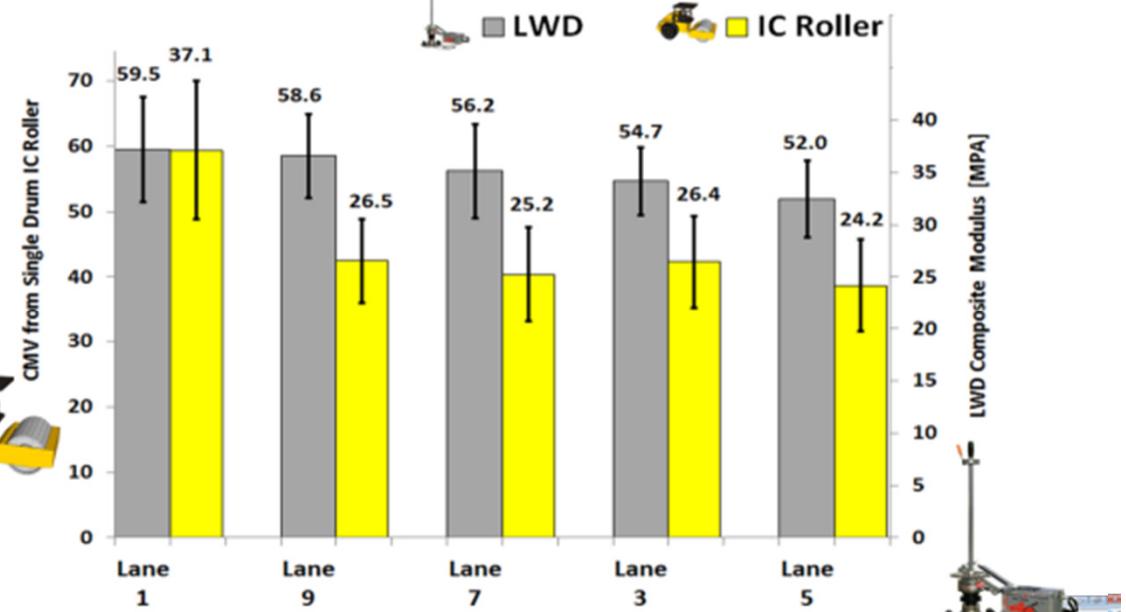


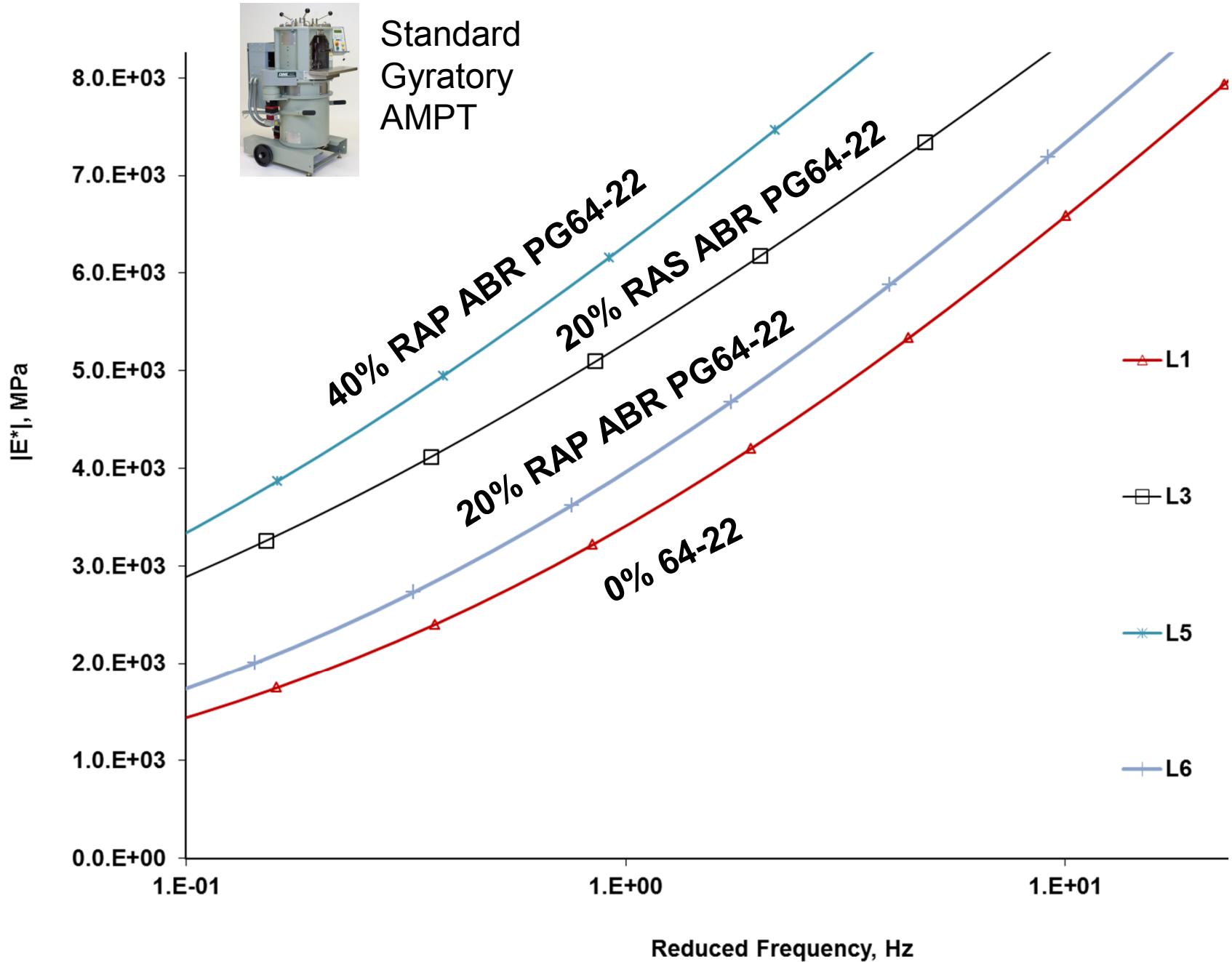
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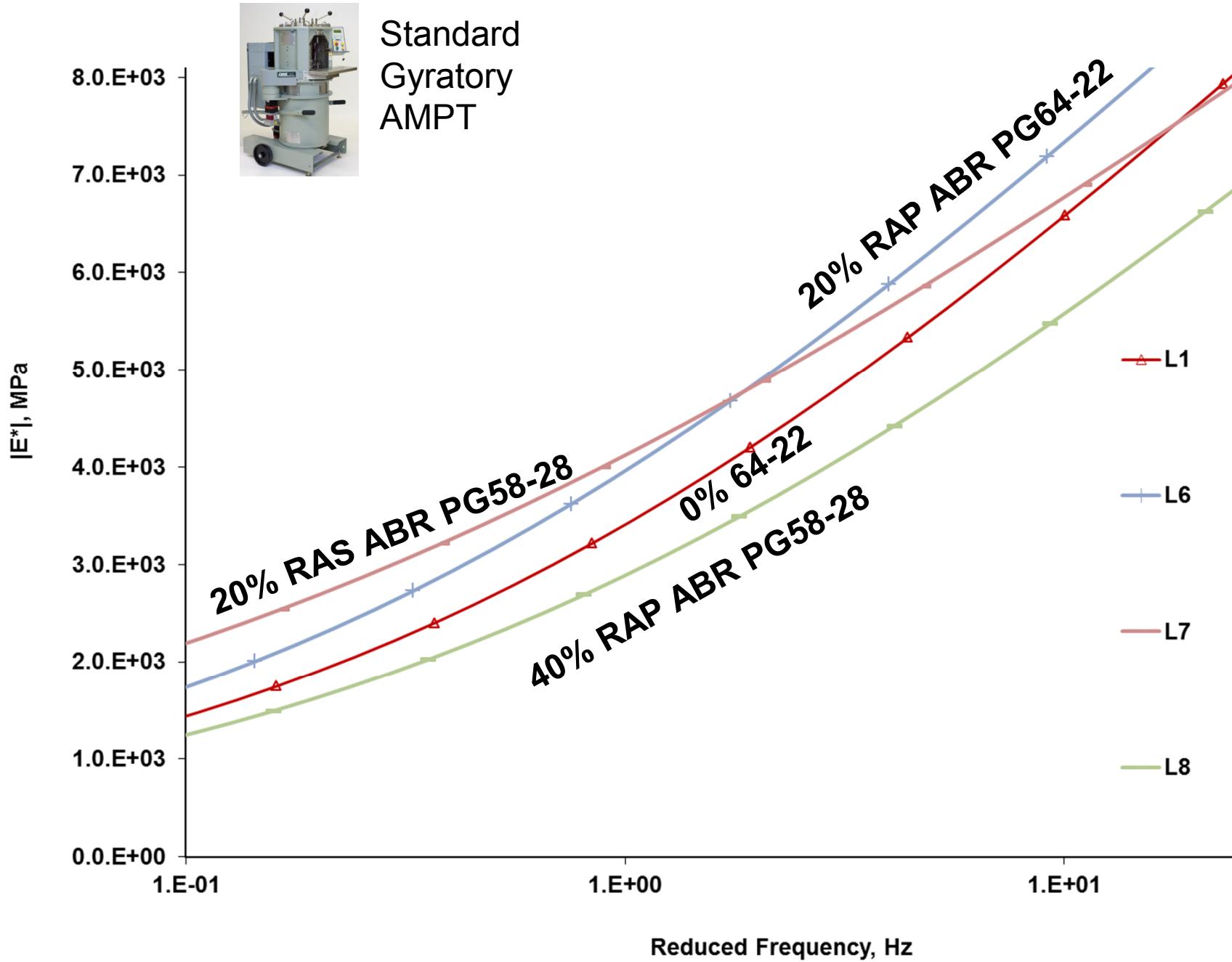


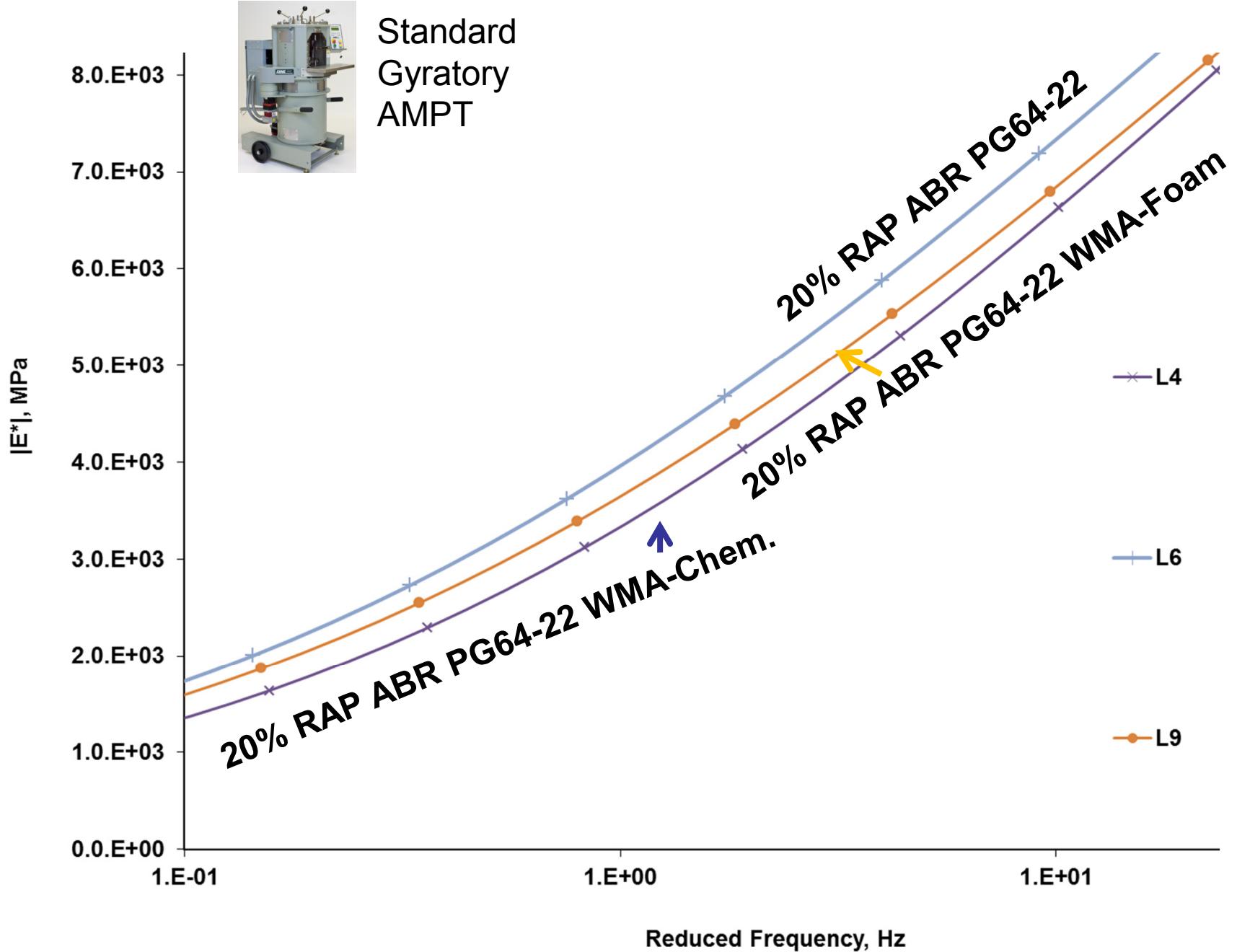


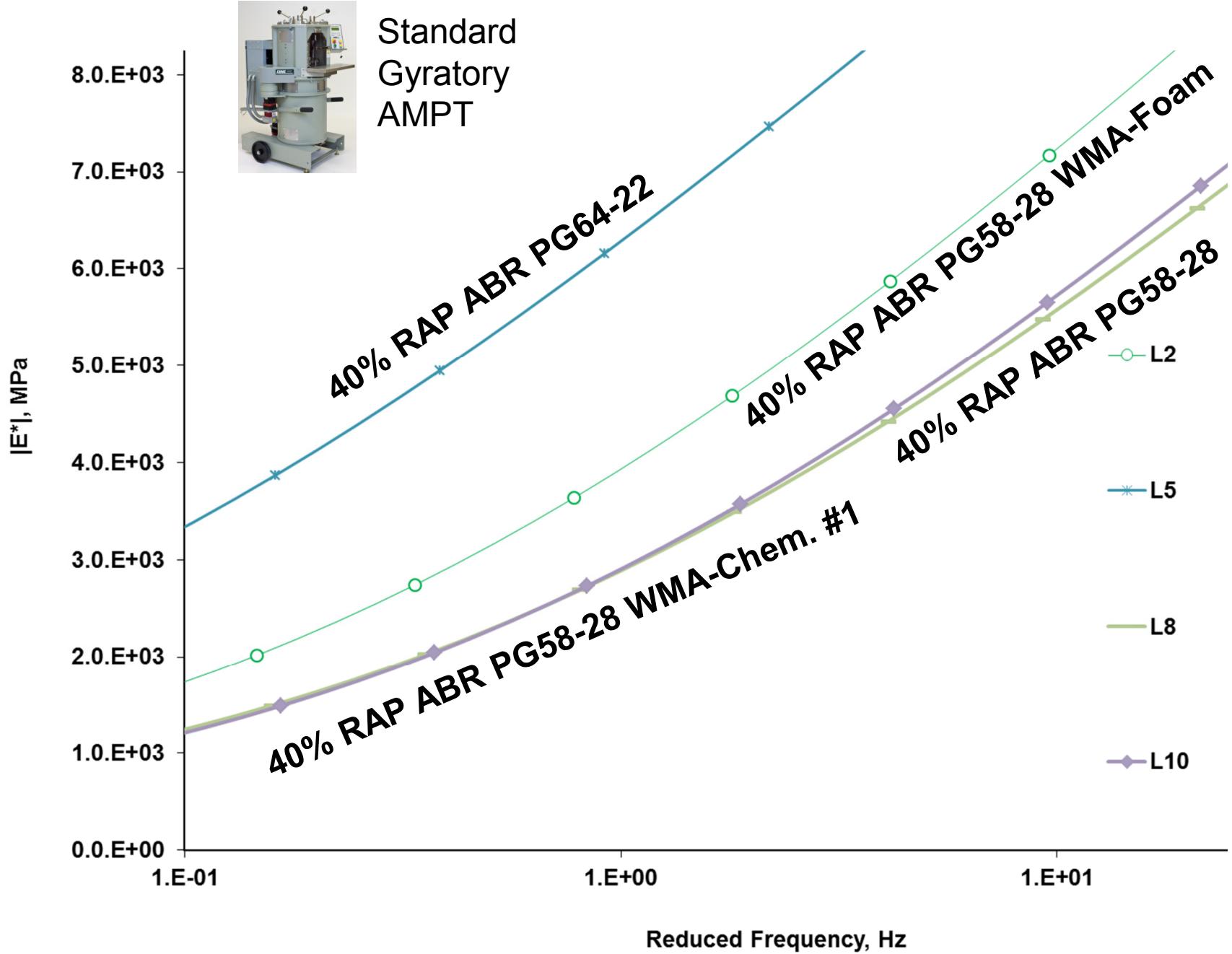
Aggregate Base Reconditioning w/ LWD, FWD, PSPA & Caterpillar IC Retrofit

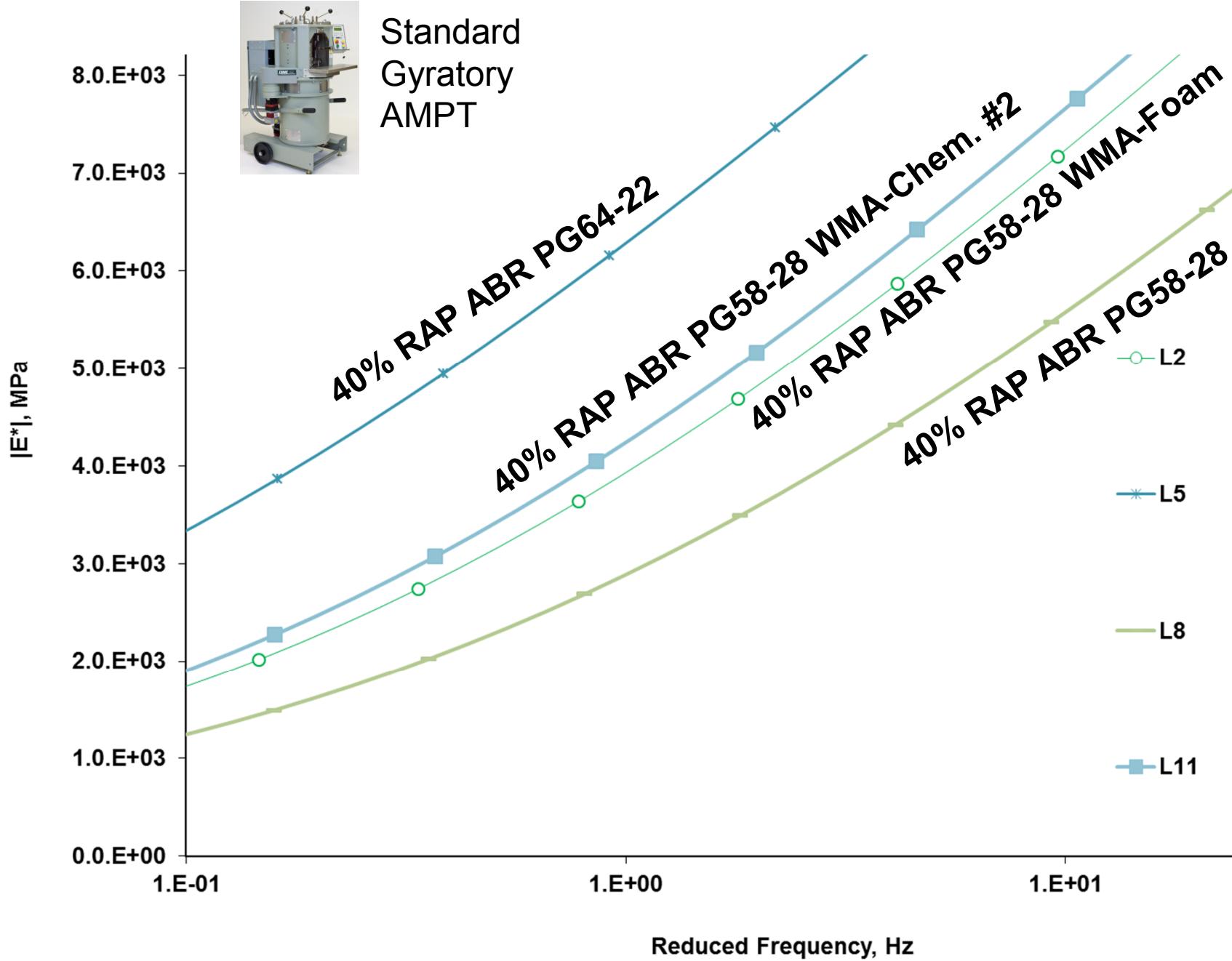


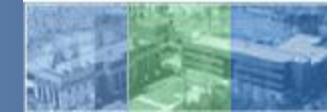




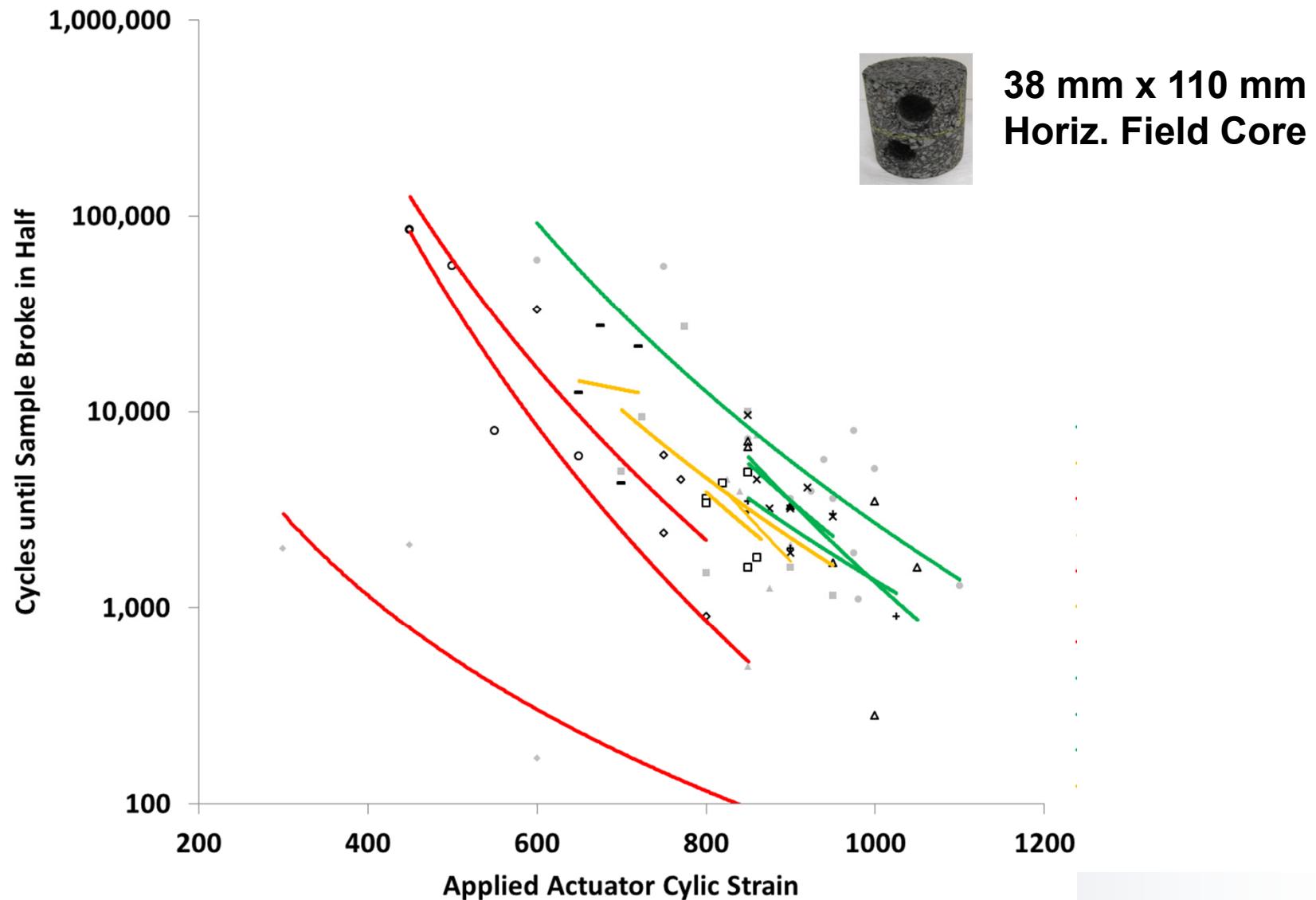






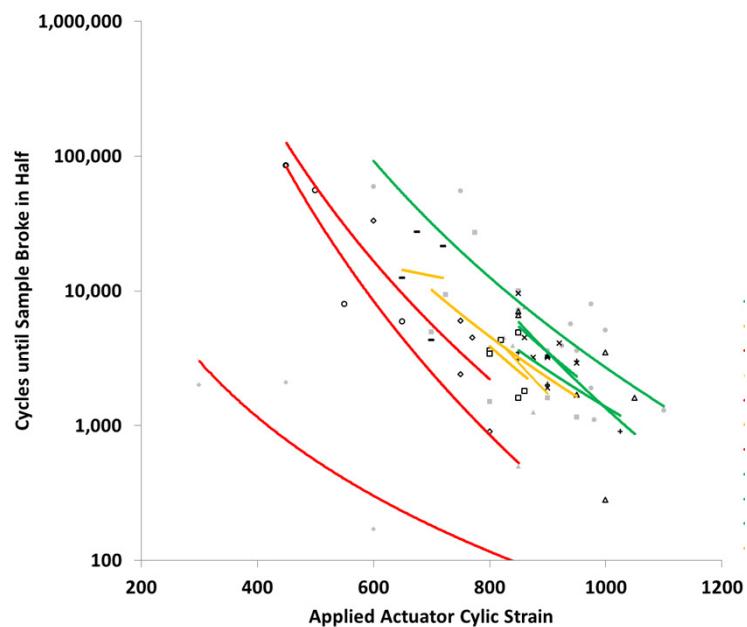


AMPT Fatigue before VECD Analysis





AMPT Fatigue before VECD Analysis



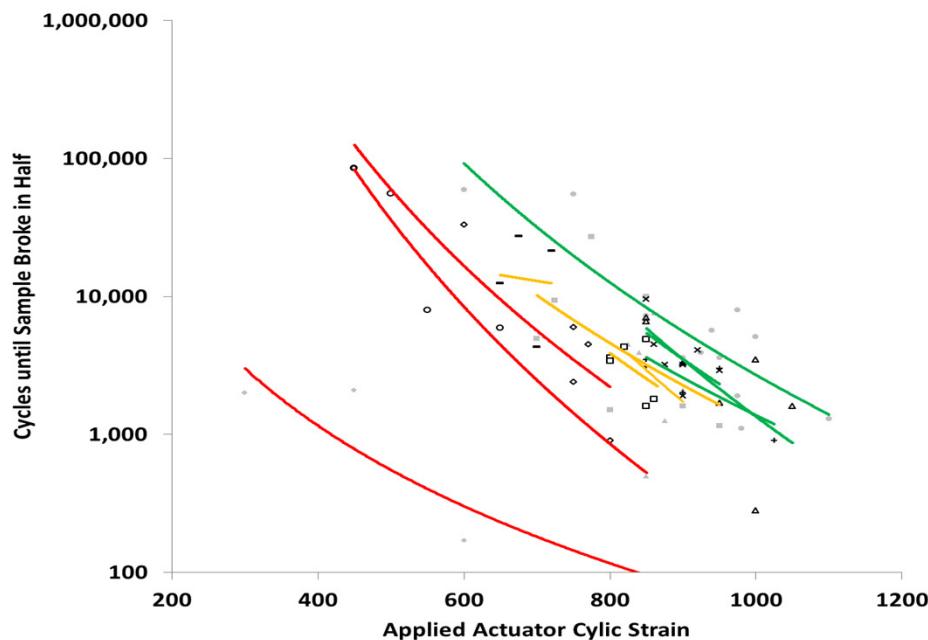
GREEN	0% Control PG64-22 40% ABR RAP PG58-28 20% ABR RAP PG64-22 WMA Foam 40% ABR RAP PG58-28 WMA Chem. #1
YELLOW	40% ABR RAP PG58-28 WMA Foam 20% ABR RAP PG64-22 WMA Chem. 20% ABR RAP PG64-22 40% ABR RAP PG58-28 WMA Chem. #2
RED	20% ABR RAS PG64-22 20% ABR RAS PG58-28 40% ABR RAP PG64-22



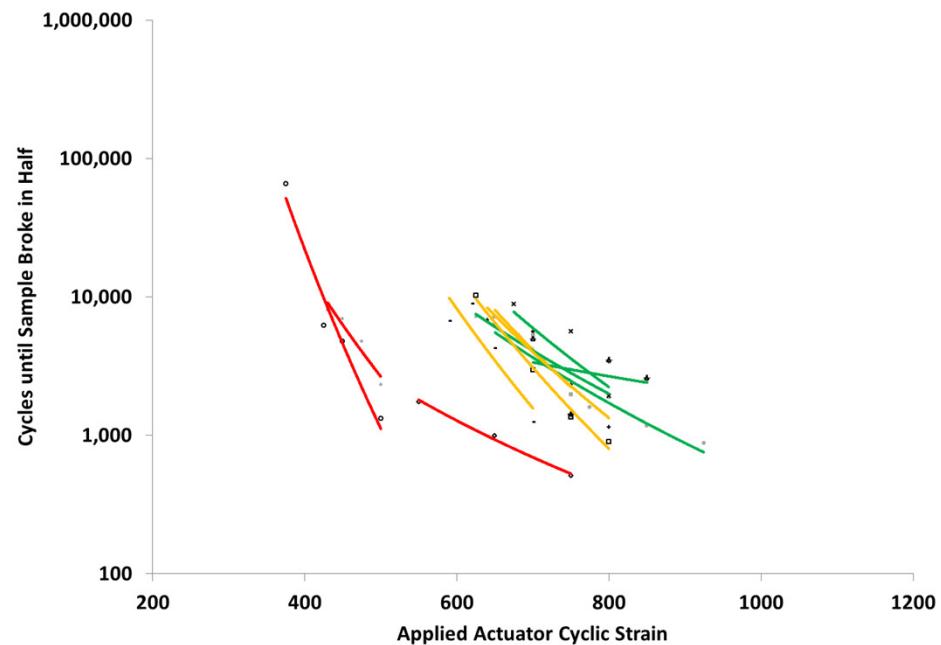
AMPT Fatigue before VECD Analysis



As-built air void content

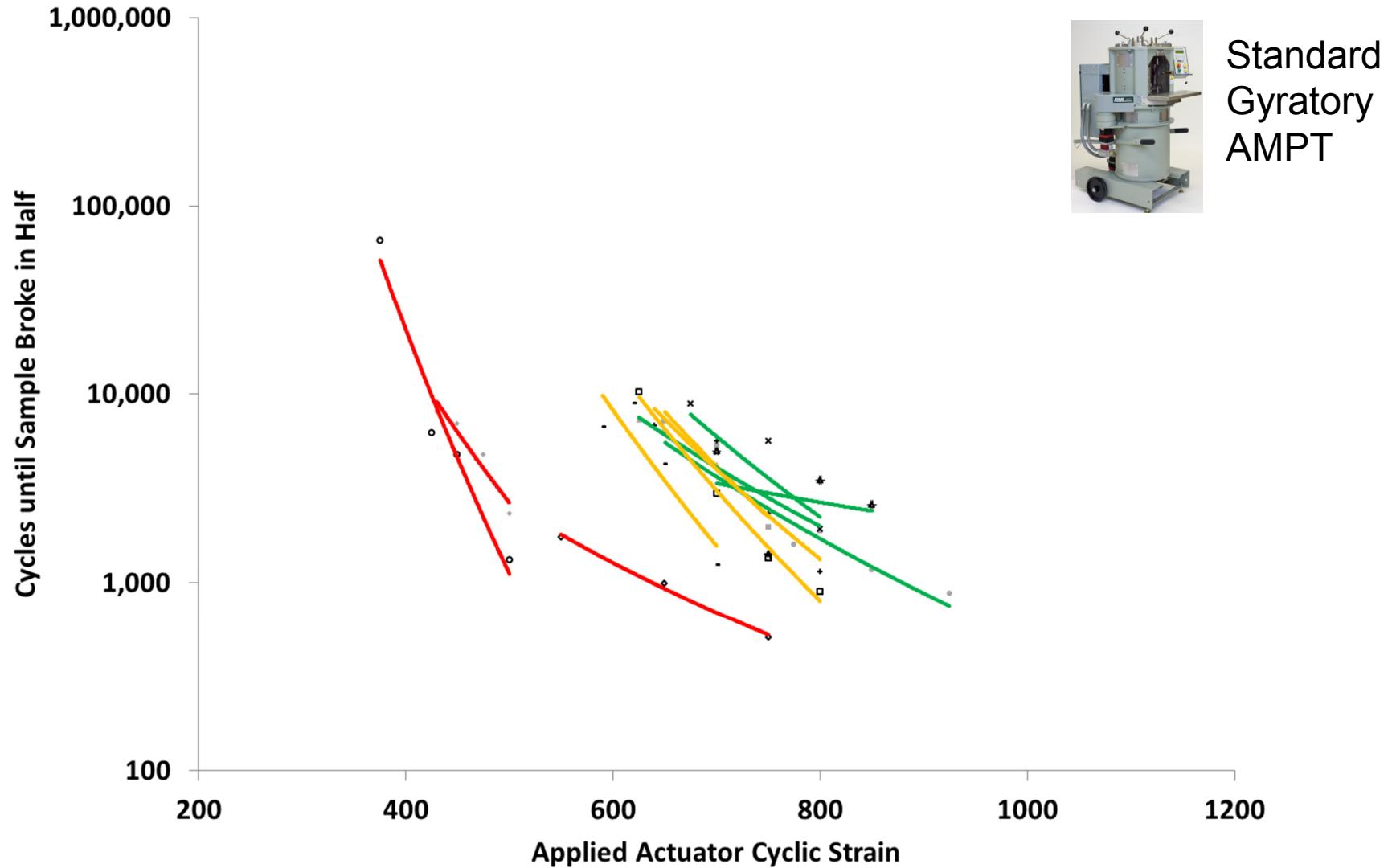


Controlled 7% air void content





AMPT Fatigue before VECD Analysis

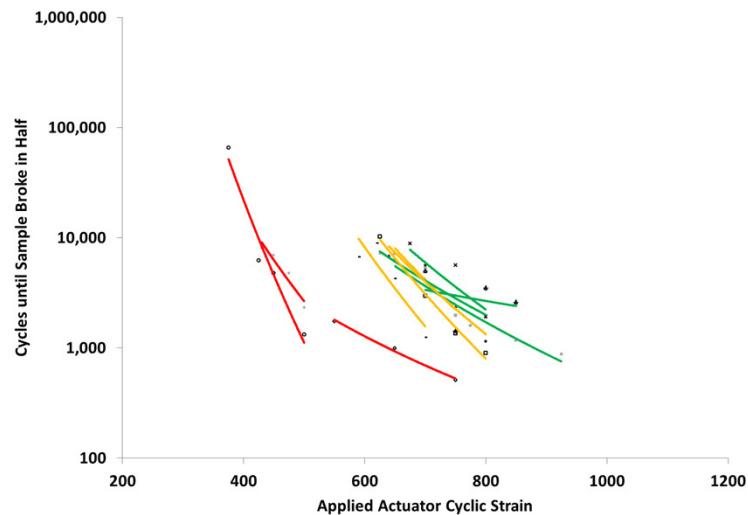




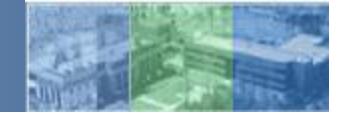
AMPT Fatigue before VECD Analysis



Standard
Gyratory
AMPT

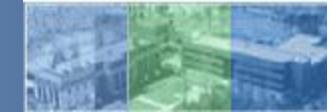


GREEN	0% Control PG64-22 40% ABR RAP PG58-28 20% ABR RAP PG64-22 WMA Chem. 40% ABR RAP PG58-28 WMA Chem. #1
YELLOW	40% ABR RAP PG58-28 WMA Foam 20% ABR RAP PG64-22 WMA Foam 20% ABR RAP PG64-22 40% ABR RAP PG58-28 WMA Chem. #2
RED	20% ABR RAS PG64-22 20% ABR RAS PG58-28 40% ABR RAP PG64-22



AMPT Fatigue without VECD Analysis

	 <p>Horizontal Field Core In-Place Density</p>	 <p>Standard Gyratory AMPT Controlled 7% air voids</p>
GREEN	0% Control PG64-22 40% ABR RAP PG58-28 20% ABR RAP PG64-22 WMA Foam 40% ABR RAP PG58-28 WMA Chem. #1	0% Control PG64-22 40% ABR RAP PG58-28 20% ABR RAP PG64-22 WMA Chem. 40% ABR RAP PG58-28 WMA Chem. #1
YELLOW	40% ABR RAP PG58-28 WMA Foam 20% ABR RAP PG64-22 WMA Chem. 20% ABR RAP PG64-22 40% ABR RAP PG58-28 WMA Chem. #2	40% ABR RAP PG58-28 WMA Foam 20% ABR RAP PG64-22 WMA Foam 20% ABR RAP PG64-22 40% ABR RAP PG58-28 WMA Chem. #2
RED	20% ABR RAS PG64-22 20% ABR RAS PG58-28 40% ABR RAP PG64-22	20% ABR RAS PG64-22 20% ABR RAS PG58-28 40% ABR RAP PG64-22



AMPT Fatigue without VECD Analysis

	 <p>Horizontal Field Core In-Place Density</p>	 <p>Standard Gyratory AMPT Controlled 7% air voids</p>
GREEN	0% Control PG64-22 40% ABR RAP PG58-28 <i>20% ABR RAP PG64-22 WMA Foam</i> <i>40% ABR RAP PG58-28 WMA Chem. #1</i>	0% Control PG64-22 40% ABR RAP PG58-28 <i>20% ABR RAP PG64-22 WMA Chem.</i> 40% ABR RAP PG58-28 WMA Chem. #1
YELLOW	40% ABR RAP PG58-28 WMA Foam <i>20% ABR RAP PG64-22 WMA Chem.</i> 20% ABR RAP PG64-22 40% ABR RAP PG58-28 WMA Chem. #2	40% ABR RAP PG58-28 WMA Foam <i>20% ABR RAP PG64-22 WMA Foam</i> 20% ABR RAP PG64-22 40% ABR RAP PG58-28 WMA Chem. #2
RED	20% ABR RAS PG64-22 20% ABR RAS PG58-28 40% ABR RAP PG64-22	20% ABR RAS PG64-22 20% ABR RAS PG58-28 40% ABR RAP PG64-22



AMPT Fatigue without VECD Analysis

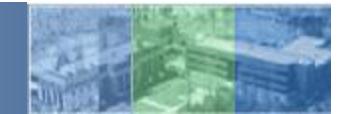
	 <p>Horizontal Field Core In-Place Density</p>	 <p>Standard Gyratory AMPT Controlled 7% air voids</p>
GREEN	0% Control PG64-22 (72, 13) 40% ABR RAP PG58-28 (75, 15) <i>20% ABR RAP PG64-22 WMA Foam (77, 19)</i> 40% ABR RAP PG58-28 WMA Chem. #1 (71, 12)	0% Control PG64-22 (72, 13) 40% ABR RAP PG58-28 (75, 15) <i>20% ABR RAP PG64-22 WMA Chem. (71, 14)</i> 40% ABR RAP PG58-28 WMA Chem. #1 (71, 12)
YELLOW	40% ABR RAP PG58-28 WMA Foam (__, __) <i>20% ABR RAP PG64-22 WMA Chem. (71, 14)</i> 20% ABR RAP PG64-22 (71, 17) 40% ABR RAP PG58-28 WMA Chem. #2 (78, 16)	40% ABR RAP PG58-28 WMA Foam (__, __) <i>20% ABR RAP PG64-22 WMA Foam (77, 19)</i> 20% ABR RAP PG64-22 (71, 17) 40% ABR RAP PG58-28 WMA Chem. #2 (78, 16)
RED	20% ABR RAS PG64-22 (91, 22) 20% ABR RAS PG58-28 (__, __) 40% ABR RAP PG64-22 (86, 22)	20% ABR RAS PG64-22 (91, 22) 20% ABR RAS PG58-28 (__, __) 40% ABR RAP PG64-22 (86, 22)



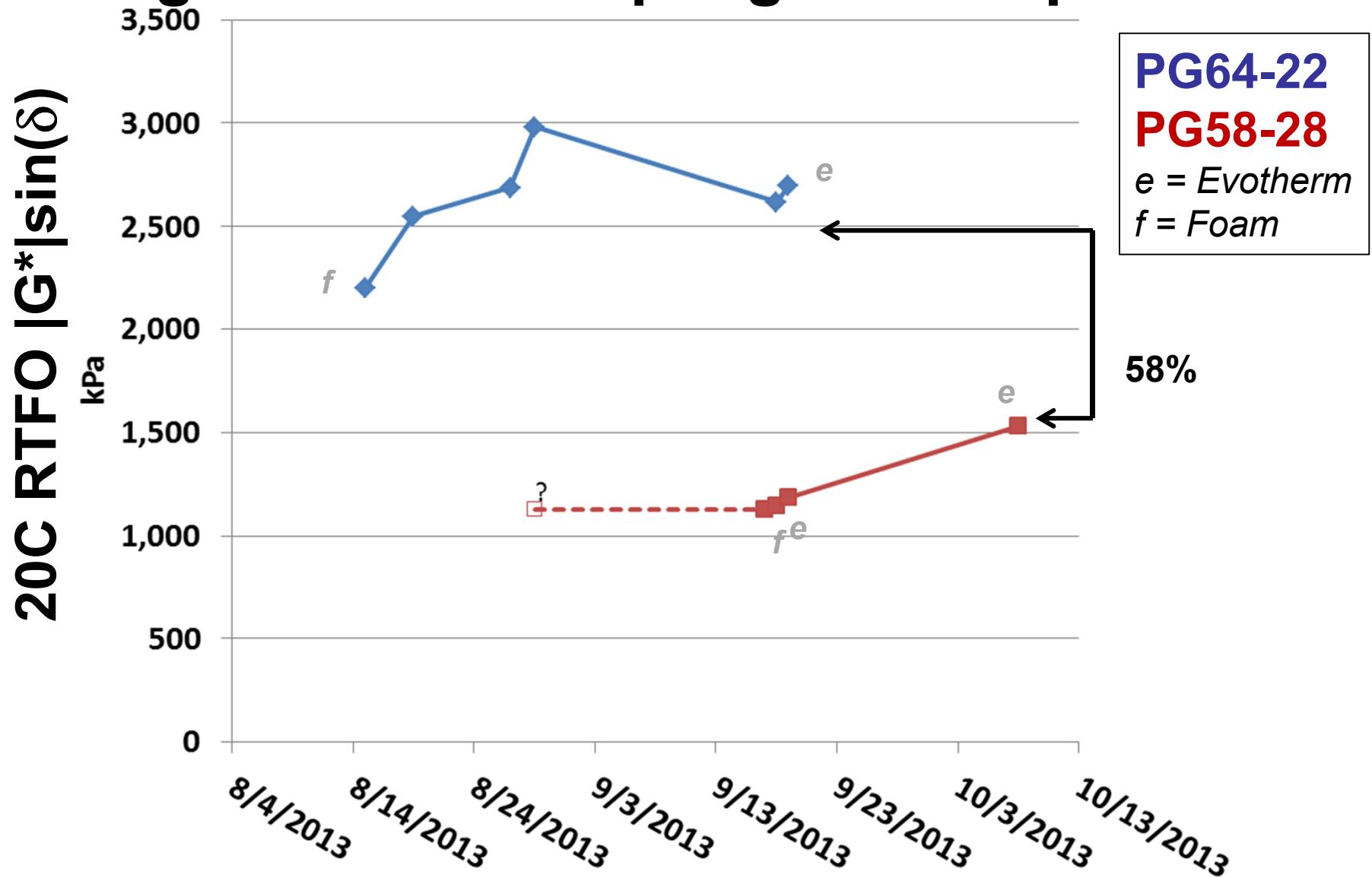
Virgin Binder Sampling and Properties



- **In-line sampling port just before entering the drum**
- **One gallon on each day of production**

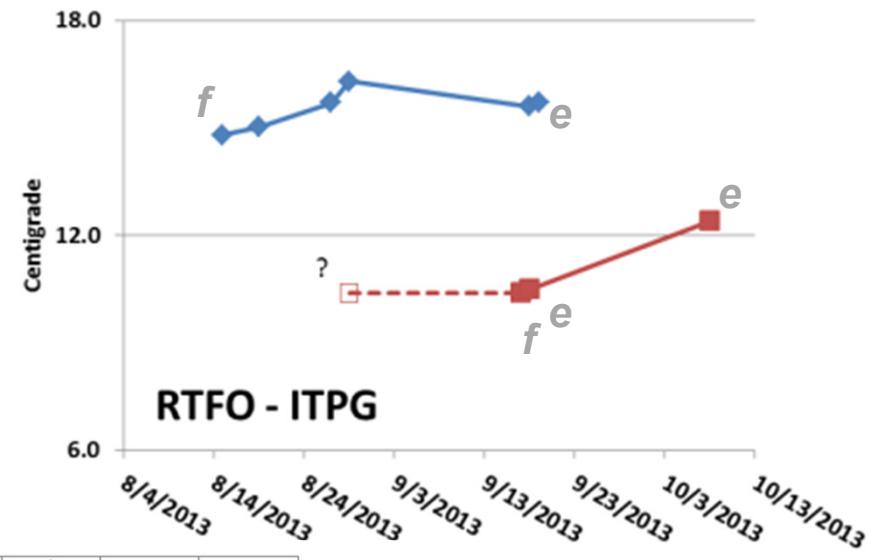
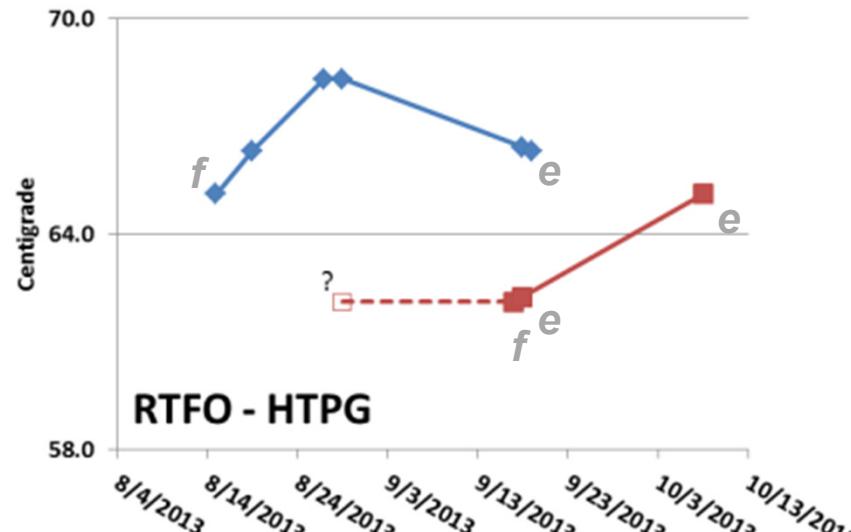


Virgin Binder Sampling and Properties

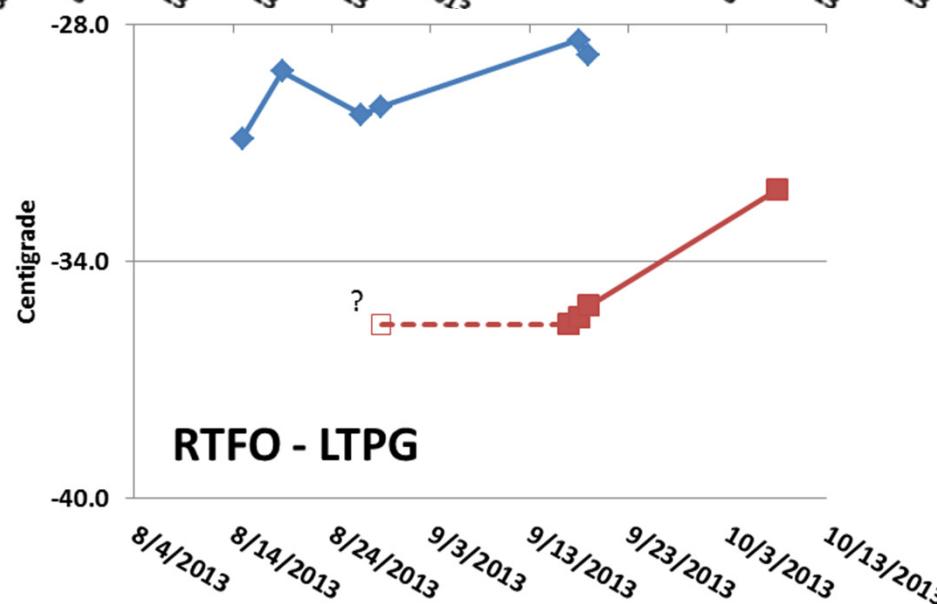


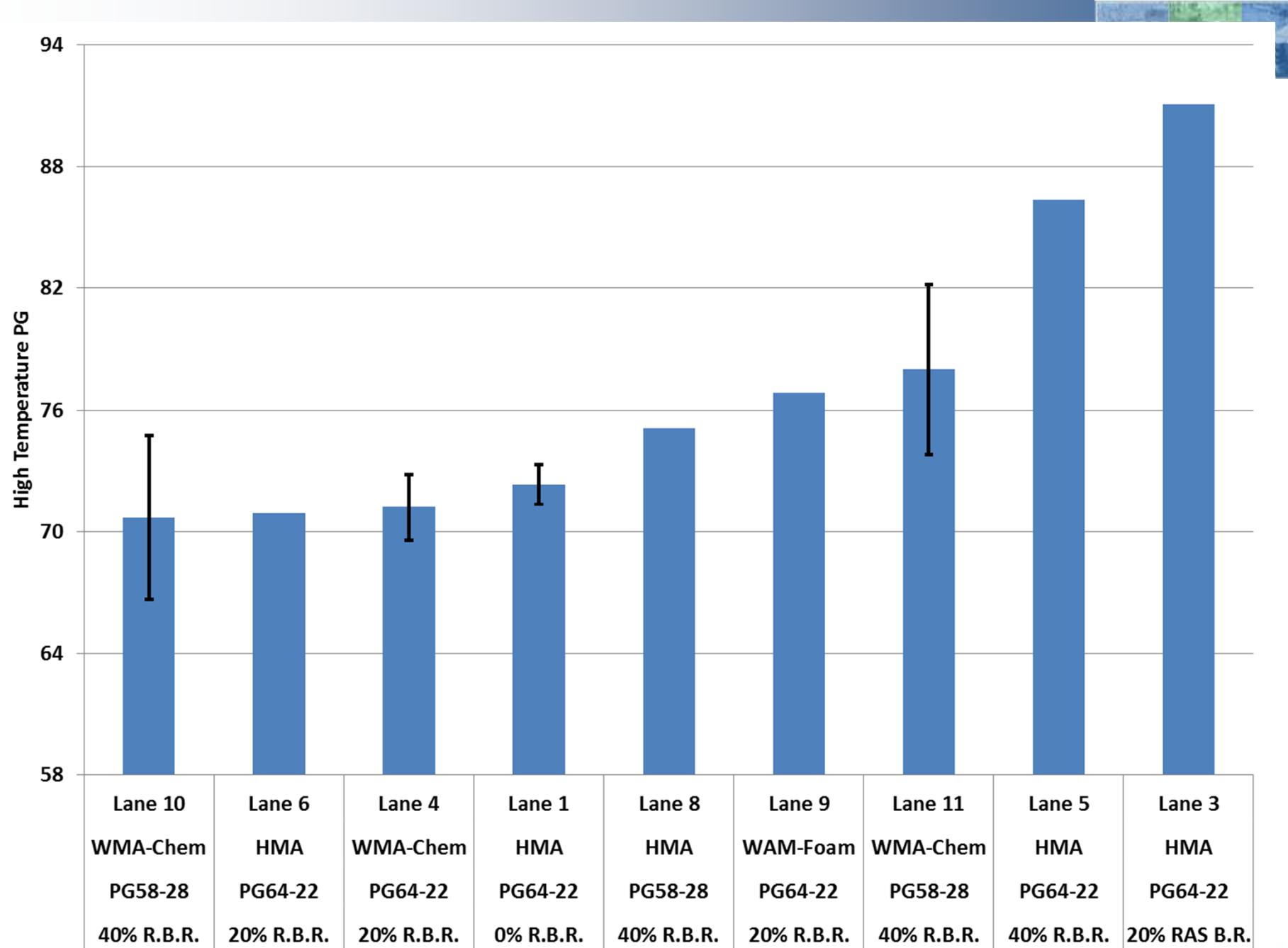


Virgin Binder Sampling and Properties



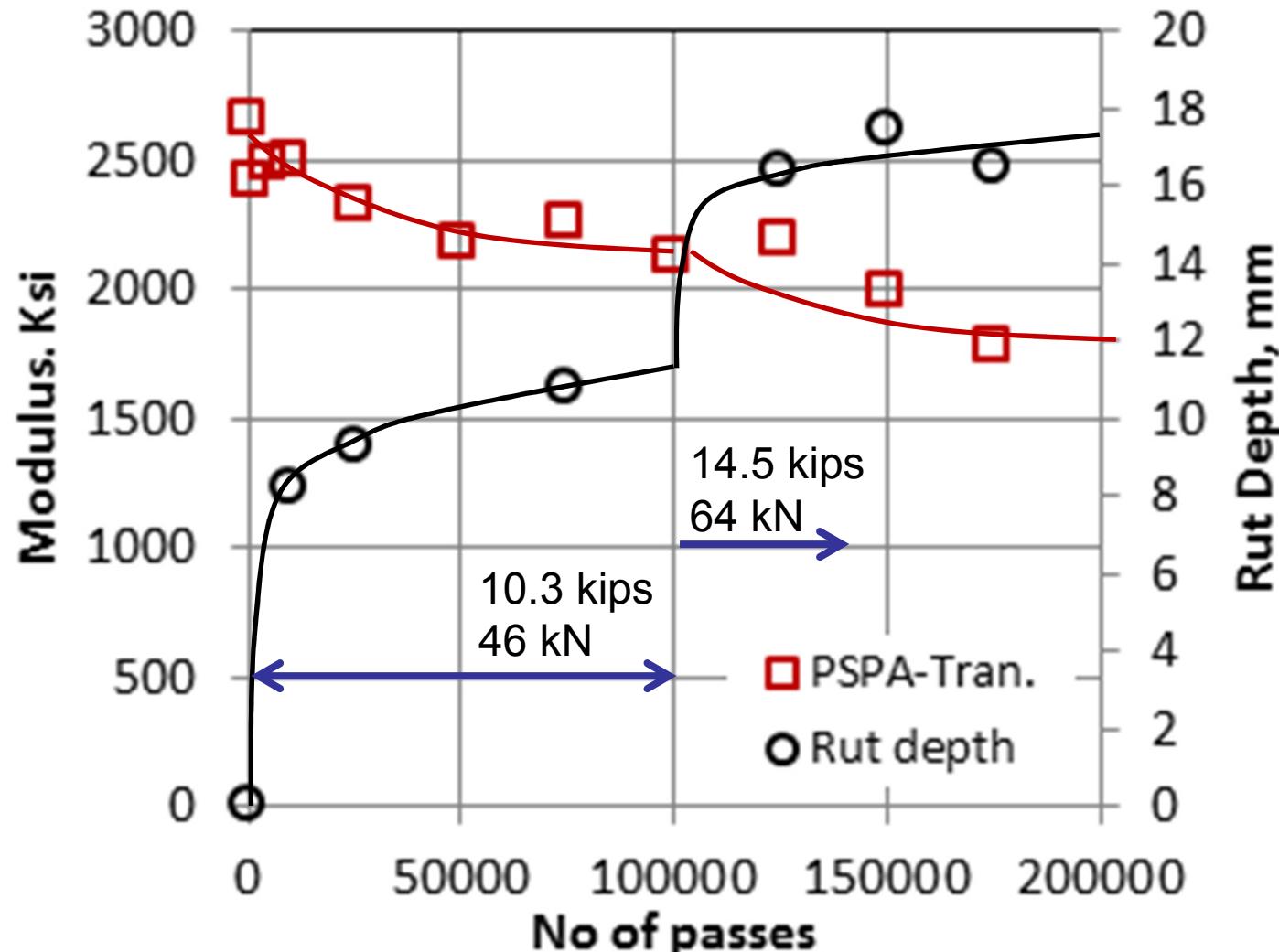
PG64-22
PG58-28
e = *Evotherm*
f = *Foam*





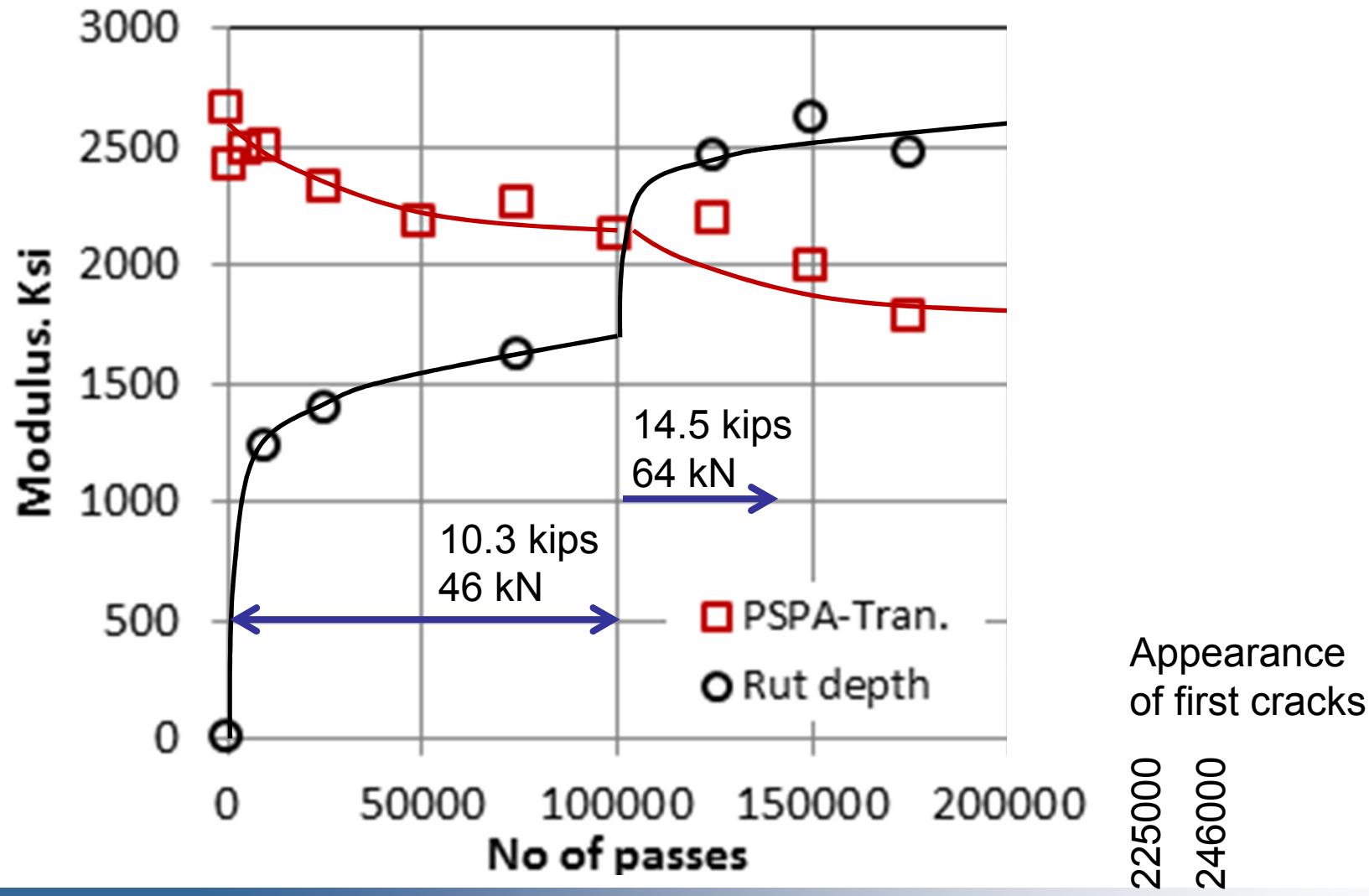


Responses and Performance in ALF Shakedown





Responses and Performance in ALF Shakedown





Responses and Performance in ALF Shakedown

